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FERRIC CHLORIDE AND ORGANIC POLY-ELECTROLYTES FOR THE REMOVAL OF PHOSPHORUS

Otto Green, et al

Grand Rapids Wastewater Treatment Plant

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The primary objective of this project was to demonstrate the feasibility and economic practicability of chemical removal of phosphorus from municipal wastewater in the 44 mgd (166,500 m^3) activated sludge plant at Grand Rapids, Michigan. The full-scale system for chemical phosphorus removal was implemented to meet water quality criteria established by the State of Michigan. Ferric chloride and polymer flocculant were introduced into the raw wastewater flow by automated systems. During the period of best performance when split dosage of chemicals was employed, residual phosphorus concentrations of less than 1 mg/l could be obtained. Total phosphorus concentrations in the final effluent were related to final clarifier overflow rates.

The nature of the chemically precipitated sludge evolved by the process was also evaluated relative to further chemical conditioning, vacuum filtration and incineration.

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FERRIC CHLORIDE AND ORGANIC POLYELECTROLYTES FOR THE REMOVAL OF PHOSPHORUS

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ABSTRACT

The primary objective of this project was to demonstrate the feasibility and economic practicality of chemical removal of phosphorus from municipal wastewater in the 44 mgd activated sludge plant at Grand Rapids, Michigan. The full-scale system for chemical phosphorus removal was implemented to meet water quality criteria established by the State of Michigan. The chemical precipitation and flocculation systems consisted, respectively, of ferric chloride and an organic polymeric flocculant. Several distinct modes of chemical treatment were evaluated. Total phosphorus concentrations below 1 mg/l in the final effluent were achieved during the best period of operation, when split addition of chemicals was practiced.

The performance and economic improvements obtained in other treatment systems associated with the chemical precipitation process were demonstrated as secondary objectives of the study. These improvements during normal flow included: reduced organic loading to the activated sludge process, reduced biochemical oxygen demand and suspended solids in the final effluent, additional removals of some heavy metals, and improved solids handling and disposal up to the limits of capacity. The nature of the chemically precipitated sludge was also evaluated relative to further chemical conditioning, vacuum filtration, and incineration.

This report was submitted in fulfillment of Grant Number 11010 ENK, by the City of Grand Rapids, Michigan under the partial sponsorship of the Environmental Protection Agency.

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SECTION I

CONCLUSIONS

1. Total phosphorus concentrations $\leq$1.0 mg/l were obtained in the final effluent when split addition of ferric chloride to both primary and secondary and flocculant addition only to the secondary system were made.

2. The total phosphorus, organic, and solids loadings to the activated sludge process were reduced by the addition of both chemicals to the raw influent wastewater.

3. Removals of heavy metals, particularly chromium and zinc, were somewhat improved by chemical treatment.

4. There was no net increase in the total iron concentration in the final effluent under normal hydraulic conditions when no primary effluent bypassed secondary treatment and when a polyelectrolyte flocculant was used.

5. The pH of the wastewater was essentially unchanged by the addition of either ferric chloride or flocculant.

6. Removals of both total phosphorus and suspended solids are reduced by excessively high primary and secondary overflow rates, but these reductions can be minimized somewhat by the addition of more ferric chloride and the addition of a polyelectrolyte flocculant.

7. Recycle streams such as digester supernate, vacuum filtrate, and waste activated sludge, can significantly influence the phosphorus removal process.

8. Greater quantities of primary sludge were produced during chemical treatment due to increased capture of solids normally present in the raw waste and of newly precipitated iron-phosphate solids.

9. Lesser quantities of waste activated sludge were produced when both chemicals were added to the raw sewage.

10. The iron and phosphorus contents of both primary and waste activated sludges increased considerably upon chemical treatment.

11. The chemically precipitated sludge was more filterable than sludge collected in the absence of the chemicals.

12. It is advantageous to provide flexibility in locating the chemical addition points during initial plant design.

13. Total chemical costs for acceptable phosphorus removal depending upon the degree of treatment ranged from $2.91-6.60/1000 cu m ($11-25/MG) of which approximately 90% was allotted for ferric chloride.

SECTION II

INTRODUCTION

The Grand Rapids City Commission responded affirmatively in June of 1968 to a request from the Michigan Water Resources Commission (WRC) to obtain at least 80 percent removal of total phosphorus by December 1972. The WRC adopted its standard from the Federal-State Conference on the pollution of Lake Michigan and its tributary basin held in Chicago in March 1968. A demonstration grant was awarded to the City of Grand Rapids in the fall of 1969 by the Environmental Protection Agency to demonstrate phosphorus removal by chemical means in an activated sludge plant in the 151,000 to 227,000 cu m/day (40 to 60 mgd) range.

The major objective of this grant was to consistently obtain a concentration of total phosphorus in the final effluent of $\leq$1.0 mg/l. Secondary objectives were to demonstrate and evaluate improvements in technical and economical performance in other unit processes produced by the chemical precipitation process. Reduced organic loading to the activated sludge process, and reduced concentrations of biochemical oxygen demand (BOD) and suspended solids in the final effluent were anticipated. It was also expected that the chemically precipitated sludge would behave differently during chemical conditioning, vacuum filtration, and incineration.

Chemical removal of phosphorus from wastewater has been described[1,2,3,4,5] and reviewed[6,7,8] in the literature. Contact between phosphate anions and multivalent metal cations result in formation of finely dispersed precipitates. Inorganic coagulants are used as precipitants. The suspended phosphorus which is initially present and that which is newly precipitated can be removed subsequently by flocculation. Organic polyelectrolyte flocculants are used to agglomerate these colloidal metal-phosphate precipitates into larger, more rapidly settling

particles. This two-step process for phosphorus removal with variations in points of chemical addition was applied to the full plant influent flow prior to primary sedimentation beginning on November 3, 1970. Ferric chloride and PURIFLOC A23 flocculant, products of The Dow Chemical Company, were the chemicals of choice based on an earlier study[9] (See section entitled Preliminary Studies).

Full-scale plant operation was planned originally for twelve consecutive months. The study commenced at a time, however, when plant expansion was underway and replacement of overloaded or unreliable equipment had not been completed. Equipment failures resulted in occasional shutdowns of the primary and secondary clarifiers, various pumping equipment, vacuum filters, and the incinerator.

Digester activity ceased completely in August 1970, prior to the initiation of chemical treatment and continued throughout the present study. Digestion failure had been occurring periodically since 1966 at the Grand Rapids Plant[10] and was not attributable to chemical additions. Exhaustive studies were made to determine the reason for this digestion failure before and during the grant without success.

Greater quantities of sludge were produced during chemical treatment due to the increased capture of solids normally present and to newly precipitated iron-phosphate solids. Because of inadequate sludge handling facilities, the phosphorus removal study was discontinued on February 25, 1971, for a period of 2-1/2 months. Emergency measures for sludge removal were applied to rid the plant of the backlog of sludge.

Several different modes of chemical treatment were practiced during the remainder of 1971. Interim activity during early 1972 consisted of installation of chemical feeding equipment in the secondary portion of the plant. Other modes of chemical treatment were evaluated over a two-month period terminating in June 1972. The most efficient mode of phosphorus removal was the split addition of ferric chloride to both primary and secondary portions of the plant and flocculant addition only to the secondary portion. This was demonstrated during a two-month extention of the original grant during January-February 1973. The details of the operation and demonstration of phosphorus removal by chemical means are discussed in this report.

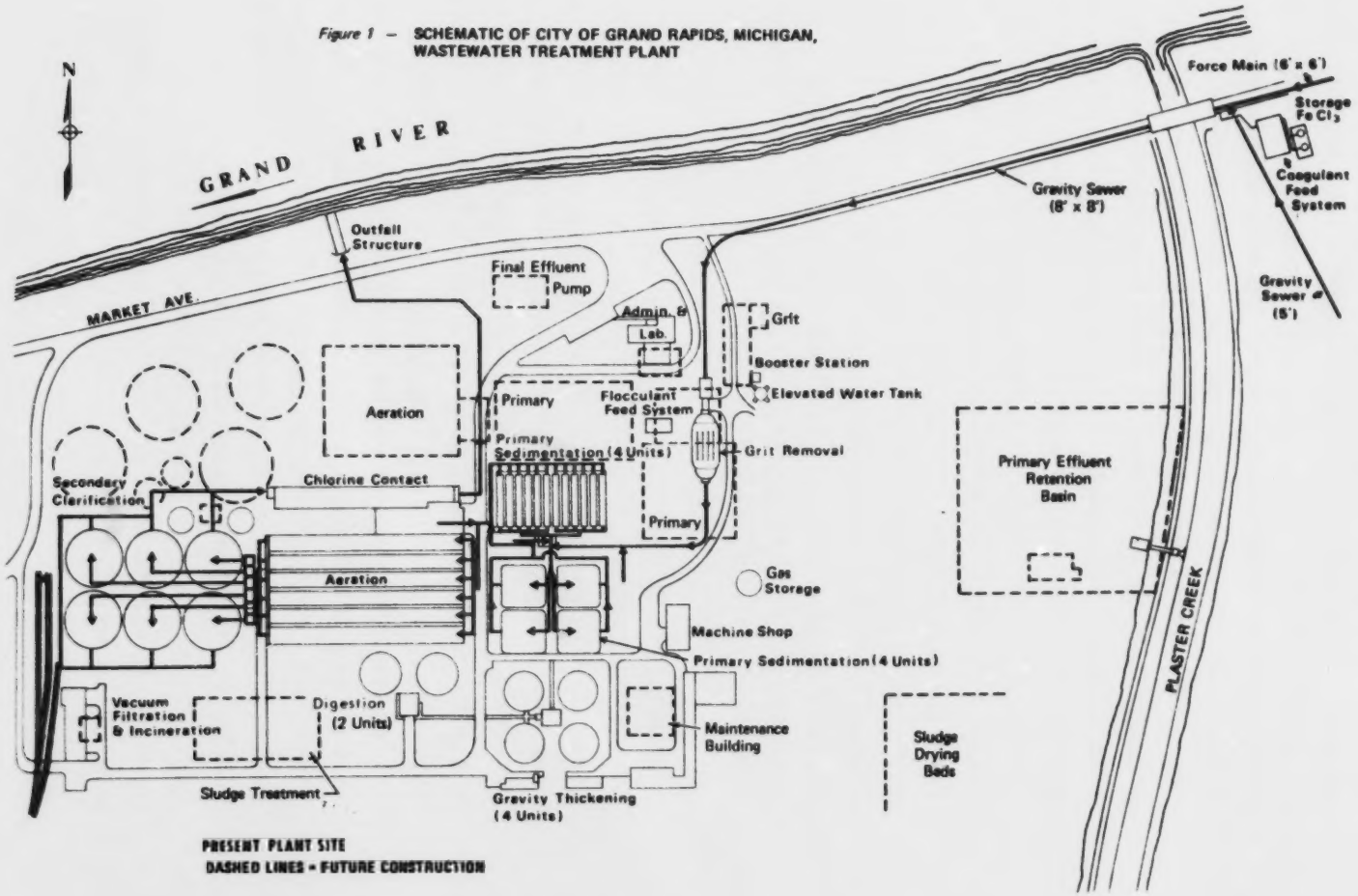
SECTION III

DESCRIPTION OF THE TREATMENT PLANT

The City of Grand Rapids, Michigan, encompassing 115 sq km (44.5 sq miles), is located in the west-central portion of the lower peninsula 72 km (45 miles) from the entry of the Grand River into Lake Michigan. The original primary plant was constructed in 1929 and expanded to include secondary treatment (activated sludge) between 1953 and 1958. A schematic of the plant is shown in Figure 1. Current expansion of facilities during the grant includes a new grit chamber and scum incinerator, additional primary tanks, final effluent lift pumps, primary effluent retention basin, and expanded laboratory facilities.

The present design capacity is 167,000 cu m/day (44 mgd) average flow, 254,000 cu m/day (67 mgd) maximum dry weather flow, and 330,000 cu m/day (88 mgd) maximum storm water flow. The plant currently treats an average flow of 150,000 cu m/day (39.5 mgd) from a connected population of 216,000. Approximately 70 percent of the flow is pumped through the Market Avenue Station to the treatment plant. The other 30 percent flows by gravity from the south side of the City of Grand Rapids and joins the major flow at a point 408 m (1340 ft) upstream from the grit chambers. A significant quantity of industrial wastewater is contributed by the manufacturers of paints, plastics, electronics equipment, furniture, and metal-working products. There are 35 metal-plating plants which contribute heavy metals, such as chromium, copper, iron, nickel, and zinc, to the total wastewater stream. An extensive program of monitoring and pretreatment regulation was initiated by the City of Grand Rapids to better define and control these industrial waste sources.

Figure 1 – SCHEMATIC OF CITY OF GRAND RAPIDS, MICHIGAN, WASTEWATER TREATMENT PLANT



PRESENT PLANT SITE
DASHED LINES = FUTURE CONSTRUCTION

Plant facilities during the study consisted of mechanical bar screens and a five-channel grit removal unit with each channel 18 m (60 ft) long equipped with proportional weirs to regulate flow. The original primary sedimentation basins consisted of four 24-m (80-ft) square clarifiers having 3.0-m (10-ft) side water depths. They were arranged with centrally aerated inlet channels. Effluent channels were located on the outside. These clarifiers were equipped with center-supported circular sludge collectors having corner sweeps. Twelve additional rectangular units were added in 1953. Each of these units measured 4.9 x 30 x 3.0 m (16 x 100 x 10 ft) (width-length-depth) and was equipped with a conventional chain-and-flight sludge collection and skimming mechanisms. The old and new primary tanks theoretically afforded a combined detention time of 1.9 hours at average flow. The overall surface settling rate was 298 cu m/day-sq m (777 gpd/sq ft) at the design flow of 167,000 cu m/day (44 mgd).

The six rectangular Y-wall spiral straight-line aeration tanks were each 9.8 x 110 x 4.6 m (32 x 360 x 15 ft) having a total volume of 29,362 cu m (1,036,800 cu ft). Retractable headers containing 3,036 saran-wrapped tubes provided fine-bubble aeration. Air was supplied by three 7.5 rps positive-displacement blowers. The six final settling tanks were each 30 m (100 ft) in diameter. They had 3.6-m (12-ft) side-water depths and were equipped with suction nozzle mechanisms for continuously removing sludge. These circular tanks had center feed and peripheral overflow weirs. The overall surface settling rate was 359 cu m/day-sq m (934 gpd/sq ft) at the design flow of 167,000 cu m/day (44 mgd). Two 1818 Kg (4,000-pound) chlorinators and a 4.0 m x 12 m x 106 m (13 ft x 40 ft x 350 ft) contact chamber provided disinfection of the final effluent.

During the grant the four flat-bottomed fixed-cover digesters served as gravity thickeners and the two 24-m (80-ft) diameter fixed-cover digesters served as holding tanks. Two Eimco vacuum filters, each with 40.9 sq m (440 sq ft) of surface, and one Nichols seven-hearth incinerator, handled 68,000 kg/day (75 ton/day) of sludge before chemical addition was begun. Ferric chloride and lime were used for chemical treatment of the sludge before filtration. The limited capacity of the incinerator necessitated trucking some of the sludge cake to landfill during a portion of the study.

SECTION IV

PRELIMINARY STUDIES

Optimum application of chemical processes for phosphorus removal requires careful control of chemical feed rates. The amount of soluble phosphorus present in the raw waste and the total waste flow is variable. The concentration of inorganic precipitant must be sufficient to precipitate the major portion of the soluble phosphorus present in the raw sewage. Excessive amounts of precipitant, however, can impair flocculation, waste chemical, and reduce phosphorus removal. The feed rate of the precipitant should be adjusted proportional to the product of the concentration of soluble phosphorus in the raw sewage and the raw sewage flow. The feed rate for the polyelectrolyte flocculant should be adjusted proportional to flow.

PHOSPHORUS REMOVAL FEASIBILITY STUDY

The feasibility of phosphorus removal by various chemical systems was determined by personnel of The Dow Chemical Company from a series of laboratory and plant studies conducted at the Grand Rapids Wastewater Treatment Plant from March 12 through March 14, 1969[9]. Laboratory tests were run using a variable-speed mixing apparatus to simulate chemical precipitation and flocculation conditions to be expected in the full-scale plant. The various chemical systems evaluated were: ferric chloride, ferrous chloride, aluminum sulfate, and sodium aluminate in conjunction with PURIFLOC A23 flocculant. Average concentrations of each inorganic coagulant in conjunction with the organic flocculant are presented in Table 1. Orders of addition, time of contact, and types of mixing and flocculation were also studied.

TABLE 1

PRELIMINARY ESTIMATES OF CHEMICAL REQUIREMENTS

Chemical	Concentration, mg/l	Concentration, lbs/million gal
Ferric chloride	15. as Fe	363. as $FeCl_3$
PURIFLOC A23 flocculant	.3	2.5
Ferrous chloride	15. as Fe	283. as $FeCl_2$
Lime	20. as CaO	167. as CaO
PURIFLOC A23 flocculant	.3	2.5
Ferrous chloride	15. as Fe	283. as $FeCl_2$
Sodium hydroxide	24. as NaOH	200. as NaOH
PURIFLOC A23 flocculant	.5	4.2
Aluminum sulfate	10. as Al	1029. as $Al_2(SO_4)_3 \cdot 18\ H_2O$
PURIFLOC A23 flocculant	.4	3.4
Sodium aluminate	15. as Al	504. as $NaAlO_2 \cdot 1\text{-}1/2\ H_2O$
PURIFLOC A23 flocculant	.4	3.3

Any one of the several inorganic coagulants in combination with the anionic polyelectrolyte flocculant were considered satisfactory to obtain the desired level of total phosphorus removal. Ferric chloride was selected over the other inorganic coagulants on the basis of both performance and economics. Average concentrations of 15 mg ferric iron/l and 0.3 mg PURIFLOC A23 flocculant/l were selected for the study. These concentrations were chosen to produce a final effluent containing one mg/l or less of total phosphorus and also meet the established WRC criterion of 80 percent removal of total phosphorus.

For successful plant scale application of the phosphorus removal process as applied prior to primary treatment, it appeared necessary to add the inorganic coagulant to the raw sewage about four minutes upstream from the point of addition of the polyelectrolyte flocculant. Laboratory estimations also were made of the flash mix and flocculant requirements of the process after the flocculant was added[9]. It was found desirable to provide a period of rapid mixing of 30 to 60 s to thoroughly disperse the flocculant, followed by a more extended period of gentle mixing to promote flocculation. Based on the detention times measured at the plant and also on previous raw sewage flocculation experience at this plant[11], all mixing criteria could be met using the existing facilities.

Initially it was decided to add ferric chloride followed by PURIFLOC A23 flocculant prior to primary sedimentation. This mode of chemical addition was chosen on the basis of the laboratory study to provide $\leq$1.0 mg total phosphorus/l in the final effluent. The expected reduction in the biological load to the secondary portion of the plant was an additional justification for chosing this mode of chemical treatment. The split addition of chemicals during both

primary and secondary treatment was selected subsequently as the preferred mode of treatment to obtain $\leq$1.0 mg total phosphorus/l in the final effluent.

DETENTION TIME STUDY

Detention times were determined in the headworks of the plant to better define intervening mixing opportunities and chemical addition points for the phosphorus removal process. Small volumes of a concentrated solution of Rhodamine B dye were introduced into the wastewater flow at various points. The times of flow of the first appearance of dye between selected points then were observed visually. Various points annotated along the flow path in the headworks of the plant prior to primary clarification are shown in Figure 5 in the next section. The detention times between these annotated points are summarized in Table 2. Additional points are described subsequently in Table 3.

TABLE 2

DETENTION TIMES AT HEADWORKS OF THE GRAND RAPIDS WASTEWATER TREATMENT PLANT

(Average design flow: 167,000 cu m/day (44 mgd)

Flow		Detention Times, s	
		Differential	Cumulative
A to B		188	188
B to C	Shown on	295	483
C to D	Figure 5	91	574
D to E		239	813

Description of Points:

A - Interceptor junction box
B - Influent sewer manhole
C - Influent grit channels
D - Effluent grit channels
E - Primary tank feeder

The following points of chemical addition were proposed on the basis of the detention time study. Ferric chloride initially was to be added to the raw sewage in the influent sewer at the manhole (Point B). PURIFLOC A23 flocculant was to be added initially in the vicinity of the grit chamber effluent (Point D). In this configuration, the inorganic coagulant would have been in contact with the raw sewage in excess of the four minutes required prior to the addition of the polyelectrolyte flocculant. An additional period of mixing of 240 s was available from the effluent of the grit chamber to the feeder channel of the primary tanks.

Permanent facilities for feeding the ferric chloride were installed near Point A located about 396 m (1300 ft) prior to the grit chambers at a point immediately downstream from the confluence of the 1.8 m x 1.8 m (6 x 6 ft) Market Avenue force main and the 1.5-m (5-ft) diameter southeast gravity-flow interceptor. Point A was chosen over Point B because of anticipated interference with ferric chloride deliveries due to construction activities.

Initially Point C was selected for flocculant addition. Because of excessive turbulence at Points D and F and preaeration before primary clarification, the addition point during Period 2 was moved successively from Point C to Points H_1 through H_8. This latter series of addition points provided optimum flocculation but some difficulty was encountered maintaining uniform flocculant distribution. All points of chemical addition are described in detail in the section entitled Chemical Storage and Handling.

SECTION V

CHEMICAL STORAGE AND HANDLING

The storage, handling and feeding equipment for both flocculant and coagulant was designed by the Engineering and Construction Services Department of The Dow Chemical Company. Construction of a steel frame building and installation of the equipment was completed by local subcontractors in the fall of 1969. This building was provided with water and electrical services. It also contained various automatic samplers as well as eye baths and safety showers.

The automatic control loop for phosphorus removal at this location is shown in Figure 2. The coagulant is added first on the basis of the product of a flow signal and a phosphorus concentration signal. The flocculant is added second on the basis of a flow signal alone. Most of the specialized instrumentation and control devices were installed by personnel of The Dow Chemical Company.

Coagulant System

The coagulant feed system is shown in more detail in Figure 3. The coagulant used was flocculation grade ferric chloride. Solution concentrations were varied seasonally depending upon anticipated storage temperatures. Deliveries were made by tank truck and stored outdoors in two 45-cu m (12,000-gallon) fiberglass-reinforced-plastic (FRP) tanks surrounded by dikes for safety purposes. Both tanks were provided with continuous level transmitters and low-level alarms to facilitate feeding and loading operations. Unloading and/or transfer pumps, and acid-proof piping and valves were provided.

Figure 2 – **AUTOMATIC CONTROL LOOP FOR PHOSPHORUS REMOVAL FROM WASTEWATER**

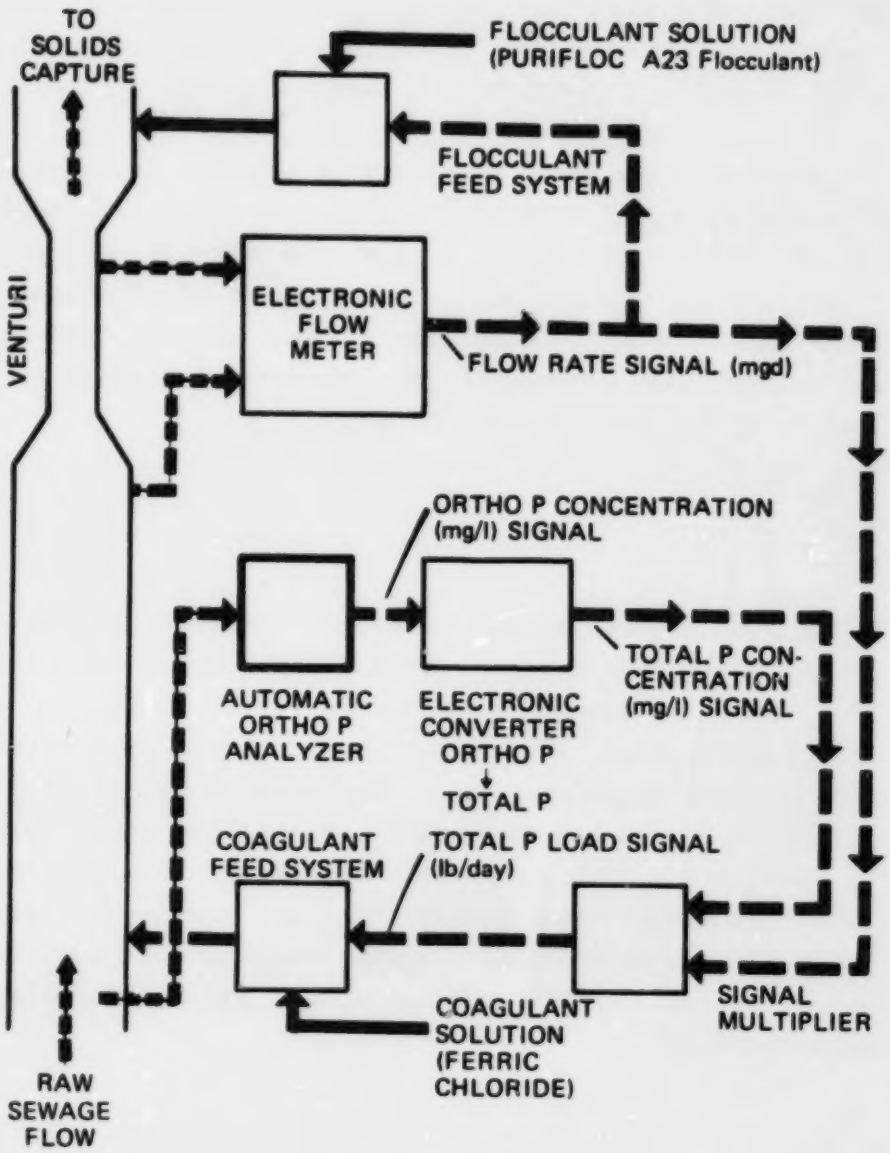
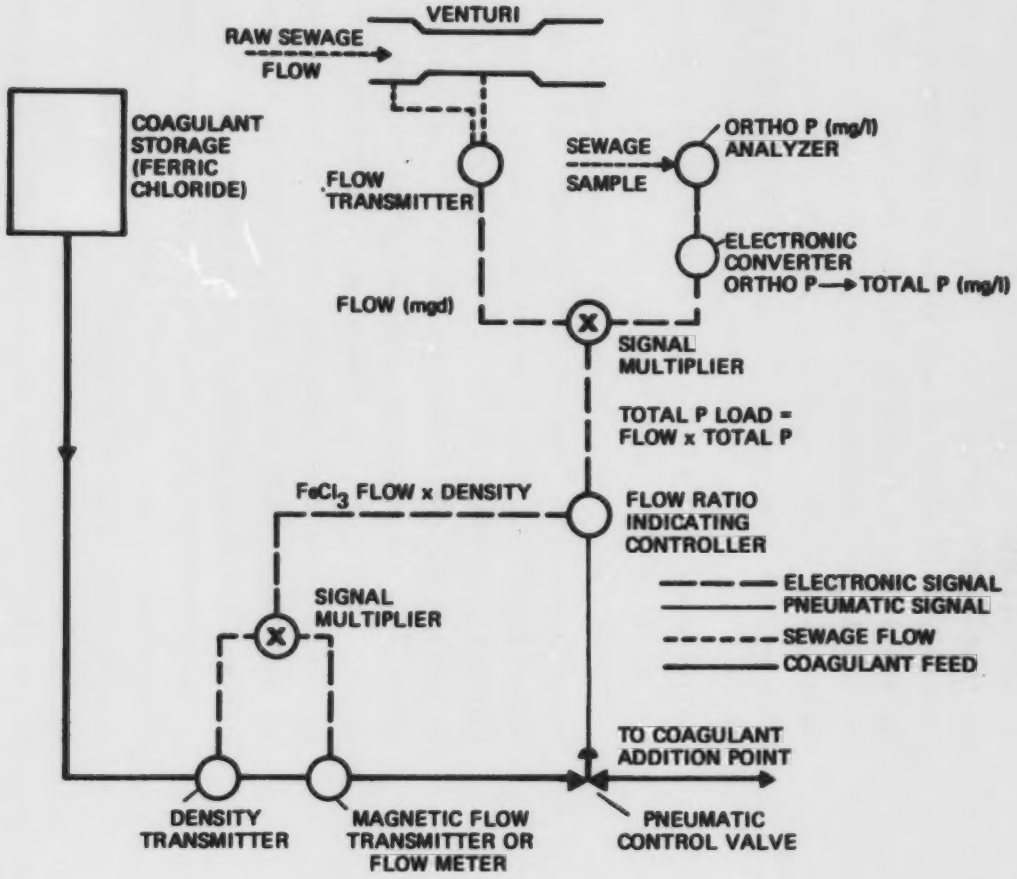


Figure 3 – **COAGULANT FEED SYSTEM**



Concentrated ferric chloride solution was added to the influent wastewater by gravity flow in proportion to the total phosphorus load. This load is the product of the total phosphorus concentration in the influent sewage and the raw sewage flow rate. An automatic ortho phosphorus analyzer provided a signal linearly related to the ortho phosphorus concentration. This signal was multiplied by the ratio of total phosphorus/ortho phosphorus concentrations. A multiplying factor of ortho/total phosphorus was obtained by statistical analysis of the data obtained for the control Period 1 (See Table 7). This modified signal was further multiplied by the influent sewage flow rate signal. The flow sensor was an electronic flow transmitter connected to an existing 1.83-m (6-ft) Venturi tube. This allowed addition of the ferric chloride solution proportional to the total phosphorus load to the plant.

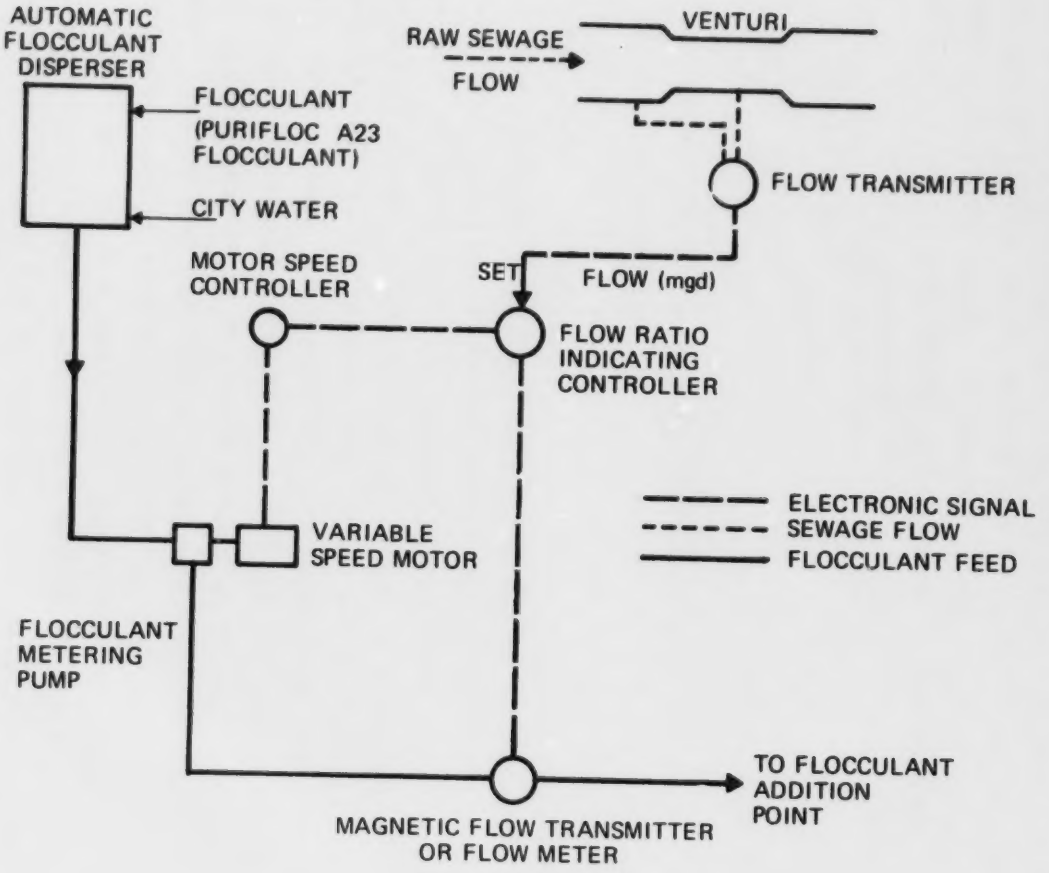
A variable ratio controller was used to proportion the ferric chloride feed. The flow control devices were pneumatically operated control valves. A signal proportional to the actual amount of ferric chloride being fed as determined by a magnetic flow transmitter was returned to the flow ratio indicating controller as feedback. Differences between the required feed rate and the actual feed rate were determined by the controller which then initiated the appropriate response by two pneumatically operated control valves. A density transmitter consisting of a gamma source and detector continuously determined the weight concentration of the ferric iron feed solution. This measurement was multiplied by the ferric chloride flow rate to provide a signal to the ratio controller which actually fed ferric iron proportional to total phosphorus.

Flexibility in the choice of addition points when designing a coagulant feed system is a requisite for proper application of chemicals throughout the plant. Based upon experiences at Grand Rapids, pneumatically operated control valves following a head/storage tank probably would not provide the necessary addition point flexibility particularly in large plants. Selection of a high-quality positive-displacement metering pump of the proper materials of construction is recommended. Such a metering system could be controlled by varying the piston stroke length according to a remote signal proportional to total phosphorus load.

Flocculant System

A schematic diagram of the flocculant feed system is shown in more detail in Figure 4. The polyelectrolyte used was PURIFLOC A23 flocculant. Solutions (0.25% by weight) were continuously prepared from bags of the dry flocculant using an automatic disperser. The resulting solution was then automatically added to the influent sewage by means of a flow-ratio-indicating controller. The drive of the solution feed pump was adjusted in proportion to the influent flow rate utilizing the same type of electronic flow transmitter previously described for the coagulant feed system. A signal proportional to the actual amount of flocculant being fed as determined by a second magnetic flow transmitter was fed back to the flow-ratio-indicating controller. The controller then determined the difference between the required feed rate and the actual feed rate and initiated the appropriate response by the pump drive. Speed indicators and low speed alarms were provided on the duplicate variable speed D.C. drives. Flow totalizers and recorders provided material balance data on both the coagulant and flocculant feed systems. It is important when selecting pump drives

Figure 4 – **FLOCCULANT FEED SYSTEM**



for this type of automatic chemical feed system, that they be properly sized to operate satisfactorily throughout the anticipated range of hydraulic conditions at the plant. Very low incoming wastewater flows requiring very low chemical feed rates may cause the variable speed motor drives to operate at extremely low rates which can result in overheating and shutdown of chemical feed. If selection of the proper variable speed motor is impossible, a metering pump with automatically controlled stroke length may be the preferred system.

Phosphorus Analyzer

The addition of an inorganic coagulant in direct proportion to wastewater flow can lead alternately to excessive or insufficient concentrations. The phosphorus concentration itself may not be proportional to flow. This may be particularly so when significant periodic industrial contributions are expected. A continuous ortho phosphorus analyzer was installed at the Grand Rapids plant, therefore, to provide a permanent record of raw influent ortho phosphorus concentration at ten-minute intervals. An electronic signal was also generated for adjustment of the ferric chloride addition rate.

This analyzer was originally developed by The Dow Chemical Company and has been licensed to Ionics, Inc.[12] for commercialization. Ortho phosphorus is determined according to the standard colorimetric test[13] using aminonaphthol sulfonic acid as the reductant ($SnCl_2$ is also compatible with the instrument). Each sample is filtered to remove suspended solids prior to colorimetric analysis as described in the subsequent section of this report. An acid wash cycle also is provided to prevent microbial growth on the internal surfaces of the instrument.

Points of Chemical Addition

The points of chemical addition evaluated during the various periods of study are noted in Figure 5 and summarized in Table 3. Flexibility in locating the chemical addition points during initial plant design is considered advantageous.

Figure 5 – **POINTS OF CHEMICAL ADDITION**

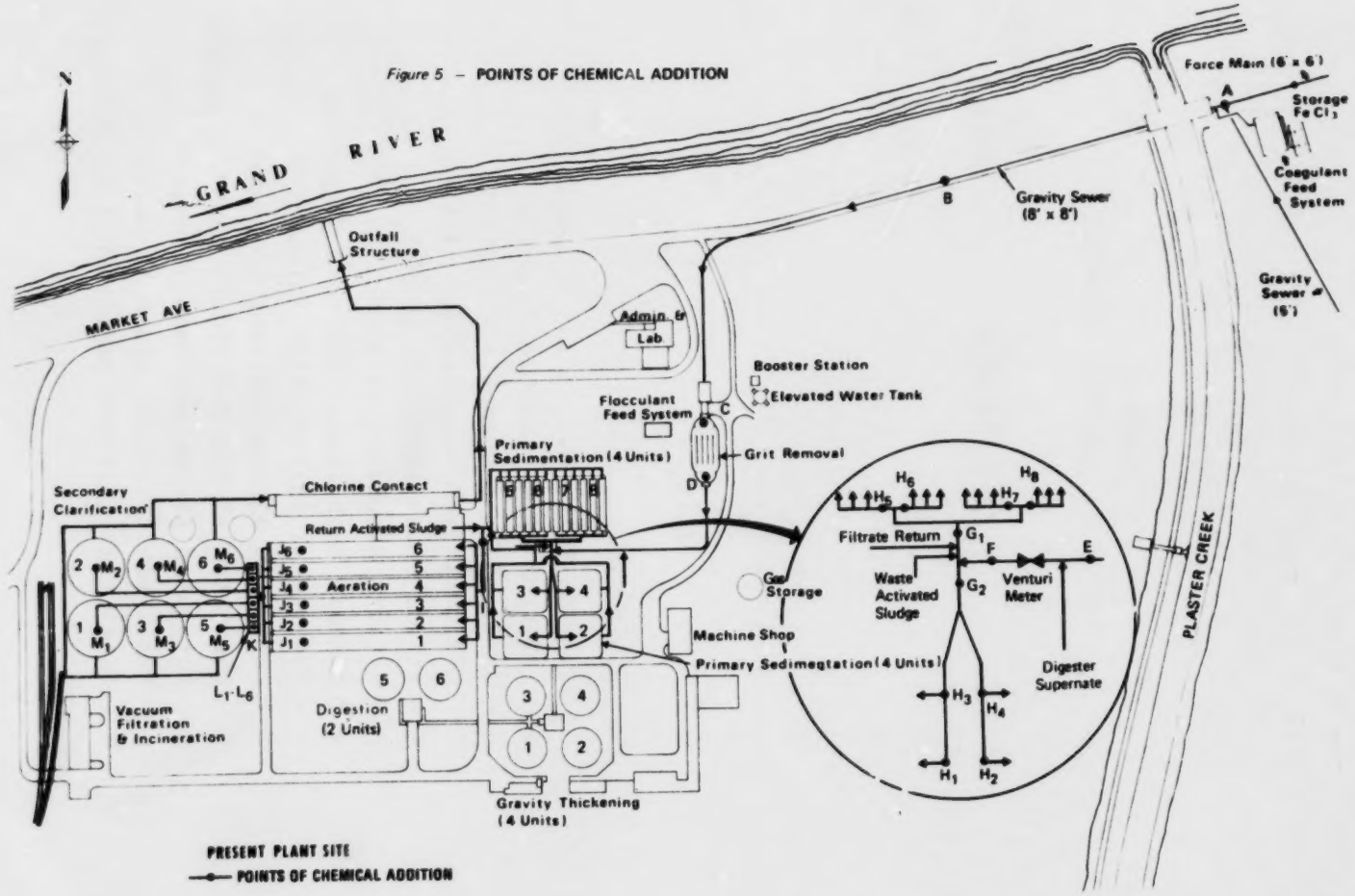


TABLE 3

POINTS OF CHEMICAL ADDITION

Period	Ferric Chloride	PURIFLOC A23 Flocculant
1	-	-
2	A	C, D, E, F, G_1-G_2, H_1-H_8
3	A	-
4	A, K, L_1-L_6	G_1-G_2
5	L_1-L_6	-
6	L_1-L_6	M_1-M_6
7	A	G_1-G_2
8	A, J_1-J_6	L_1-L_6

Description of Points:

A - Interceptor junction box (1 point)
B - Influent sewer manhole (1 point)
C - Influent grit channels (1 point)
D - Effluent grit channels (1 point)
E - Primary tank feeder (1 point)
F - Venturi discharge (1 point)
G - Primary tank feeder effluent (2 points)
H - Individual primary tank influent (8 points)
I - Activated sludge influent (1 point)
J - Activated sludge individual tanks (6 points)
K - Activated sludge effluent (1 point)
L - Final tank Parshall flume (6 points)
M - Final tank influent center well (6 points)

SECTION VI

SAMPLING AND ANALYTICAL PROCEDURES

The raw influent was automatically sampled (Chicago Pump Automatic Sampler) before screening and grit removal at a rate of 27.5 ml/1000 cu m (25 ml/240,000 gallons) of wastewater. After January 1972, hourly grab samples were taken subsequently after screening and grit removal. This change was necessitated after heavy earth moving equipment caused a collapse of the intake line buried under a permanent roadway. The sample size during this latter period was varied according to the total influent flow. The nitrogen series and pH were determined and determinations of the various phosphorus species were repeated for grab samples of influent, primary effluent, and final effluent collected each Wednesday at 8:00 AM. Bacterial analyses of final effluent were made on daily grab samples collected at 6:00 AM and at 2:00 PM.

An elaborate sample handling system was important for the optimum control of chemical addition and the reliable operation of the ortho phosphorus analyzer. A relatively trouble-free "trash pump" was installed in a sump near the combined sewer upstream of all possible chemical addition points. Approximately 2.5 l/s (40 gpm) was continuously delivered to the control building and passed through a 0.635 cm (1/4 in) screen for removal of rags and paper, etc. This screen was installed in a 208-l (55-gal) drum for ease in routine cleaning. A second pump then delivered screened raw sewage from this drum at .63 l/s (10 gpm) to the automatic sampler described above which operated in proportion to flow. A portion of the flow from this second pump was also continuously sent to the ortho phosphorus analyzer after first passing through a motor-driven self-cleaning filter to remove additional suspended solids. Sample lines to the analyzer from this filter were washed periodically with a dilute acid solution to prevent algal growth on glassware.

Primary effluent and final effluent were automatically sampled throughout the study. During periods of high flow some primary effluent bypasses secondary treatment and is combined with secondary effluent prior to chlorination. The final effluent sample, therefore, can be a blend of primary bypass and secondary effluent during high flow. Final effluent and secondary effluent are synonymous during normal flow of 167,000 cu m/day (44 mgd). Samples of primary effluent and final effluent were collected each hour in proportion to flow. Sample volumes ranged from a minimum of 25 ml/20 min to a maximum of 25 ml/5 min.

Composite samples of mixed liquor, return sludge, and waste sludge were automatically collected. A timer was used to activate the sampling device for 2-1/2 min out of every 10-min period. A daily grab sample of mixed liquor was also taken at 8:00 AM. Composite grab samples of raw and digested sludges were collected manually by the operator at 10-min intervals during sludge pumping. Composite samples of vacuum filter cake were collected hourly by the operator. Five separate samples were collected across the belt and stored in a covered container. A separate composite was made from each sludge source.

Various analytical tests listed in Table 4 were performed to evaluate the effects of the chemical precipitation/flocculation process throughout the plant. Most of these tests were performed on a daily basis prior to and during the study[14]. The analytical procedures were performed in accordance with recognized standard methods unless otherwise indicated. Details of these analytical tests are provided in Appendix A.

TABLE 4

ANALYTICAL TESTS PERFORMED

1. Ortho Phosphorus
2. Poly Phosphorus
3. Soluble Phosphorus
4. Suspended Phosphorus
5. Total Phosphorus
6. Biochemical Oxygen Demand (BOD_5)
7. Chemical Oxygen Demand (COD)
8. Total Suspended Solids (Non-Filterable Residue)
9. Volatile Suspended Solids
10. Total Solids
11. Heavy Metals
12. Metals in Sludge
13. Total Cyanide
14. Ammonia Nitrogen
15. Total Nitrogen
16. Nitrate Nitrogen
17. Nitrite Nitrogen
18. Alkalinity
19. Chloride
20. Chlorine Residual
21. Methylene Blue Active Substances in Sewage (MBAS)
22. Grease and Oil in Sewage
23. Grease Content of Sludges
24. Hydrocarbon and Fatty Matter Content of Grease
25. Volatile Acids
26. Total Coliform Group
27. Fecal Coliform Group
28. Fecal Streptococcal Group

SECTION VII

PROCESSING OF THE DATA

The chronology of the present study is presented in detail in Table 5. It consists of a year-long control period and ten periods of chemical treatment during which any one of seven modes of chemical addition was used. Period 2 is subdivided further into four periods due to intermittent operations. Period 5 is subdivived into two periods, each having significantly different ferric iron concentrations. The beginning and ending days of all periods are denoted in two ways: the usual month-day-year notation and a sequential calendar scale. The original contract began on day 182 (July 1, 1969) and ended on Day 1277 (June 30, 1972). The supplemental Period 8 was conducted on days 1462-1520 inclusive (January 1, 1973-February 28, 1973). All values for each variable and each location, if applicable, were subjected initially to probability analysis as described in Appendix B.

The mean values listed in Tables 6-11 were determined for groups of selected data. The columns labeled "All" are listings of mean values calculated from the individual mean values for the untreated raw influent for four subperiods in the case of Period 2 or for all of six selected periods of study (1-6). In this way, any significant differences existing between the raw influent mean for any given period and the collective raw influent mean for the six selected periods can be determined for any parameter. Extreme differences which exist are due either to changing waste characteristics due to pretreatment or rainfall, or to operational changes within the plant such as chemical additions or units out of service.

TABLE 5

CHRONOLOGY OF OPERATION

Date		Days		Comments
From	To	From	To	
07-01-69	06-30-70	182 -	546	Period 1: No Chemical Treatment
07-01-70	11-02-70	546 -	671	Interim Activity
11-03-70	02-25-71	672 -	786	Period 2A: Metal + Flocculant Addition to Primary
02-26-71	05-09-71	787 -	859	Interim Activity: Removal of sludge backlog; high river required plant shutdown
05-10-71	05-25-71	860 -	874	Period 2B: Metal + Flocculant Addition to Primary
05-26-71	06-06-71	875 -	887	Interim Activity: Removal of sludge backlog
06-07-71	10-20-71	888 -	1023	Period 2C: Metal + Flocculant Addition to Primary
09-09-71	09-13-71	982 -	986	Period 7: Metal + Anionic Flocculant Addition to Primary + Cationic Flocculant Addition to Secondary; Concurrent with Period 2C
10-21-71	12-09-71	1024 -	1073	Period 3: Metal Addition only to Primary
12-10-71	12-15-71	1074 -	1079	Period 4: Split Addition of Metal to Both Primary and Secondary + Flocculant Addition only to Primary
12-16-71	12-29-71	1080 -	1093	Period 2D: Metal + Flocculant Addition to Primary
12-30-71	04-11-72	1094 -	1197	Interim Activity: Construction of new grit chambers and other new facilities
04-12-72	04-17-72	1198 -	1203	Period 5A: Metal Addition only to Secondary
04-18-72	04-30-72	1204 -	1216	Period 5B: Metal Addition only to Secondary
05-01-72	05-09-72	1217 -	1225	Period 5A: (continued)
05-10-72	06-03-72	1226 -	1250	Period 6: Metal + Flocculant Addition to Secondary
06-04-72	06-30-72	1251 -	1277	Interim Activity: End of Contract
01-01-73	02-28-73	1462 -	1520	Period 8: Split Addition of Metal to Both Primary and Secondary + Flocculant Addition only to Secondary

The collective means for the 76 parameters listed on Tables 6-11 represent a statistical treatment of over 58,000 individual values. Representative listings of tabulated data are provided in Appendix C. The majority of these daily values were obtained by various direct chemical analyses. The average daily flow was determined directly from recorder charts.

Poly phosphorus and suspended phosphorus values were calculated as the differences, respectively, between soluble and ortho phosphorus values, and between total and soluble phosphorus values. Overflow rates were calculated knowing flow, clarifier sizes, and number of clarifiers in service on a given day. Detention times and weir overflow rates were also calculated but are not tabulated in Appendix C or these tables of mean values. Percentage removals of the various phosphorus species, heavy metals, biochemical oxygen demand, and suspended solids were also calculated from mean concentrations and are tabulated subsequently in Tables 14-16.

Total phosphorus loadings (Table 6) were calculated using mean concentrations (Table 6) and mean flows (Table 9). Chemical costs (Table 8) were calculated using mean flows (Table 9) and book prices for ferric chloride ($3.70/cwt 100% $FeCl_3$) and PURIFLOC A23 flocculant ($0.85/lb) plus freight from Midland to Grand Rapids, Michigan ($0.355/cwt 42% $FeCl_3$). Mean total phosphorus loadings (Table 6) and mean flows (Table 9) were used to calculate costs on other bases. Organic and solids loadings (Table 10) were calculated using mean concentrations (Table 6) and mean flows (Table 9). The distributions of the various sludges (Table 17) were either taken directly from the monthly summary sheets of plant operation or subsequently calculated.

TABLE 6

MEAN VALUES FOR PHOSPHORUS SPECIES AND TOTAL PHOSPHORUS LOADINGS

	PERIOD												
	1	2A	2B	2C	2D	ALL 2	3	4	5A	5B	6	8	ALL (1-6)
Ortho Phosphorus, mg/l:													
Raw Influent	2.5	2.0	1.9	2.7	1.9	2.3	2.6	1.8	1.7	1.6	1.6	1.8	2.1
Primary Effluent	2.5	.4	.8	.5	.8	.5	.5	.3	1.6	1.2	1.4	.6	-
Final Effluent	2.4	.4	.7	.4	.4	.5	.3	.2	.7	.4	.8	.2	-
Poly Phosphorus, mg/l:													
Raw Influent	2.5	2.7	4.0	2.3	.9	2.4	1.2	1.6	1.8	1.8	1.7	-	2.0
Primary Effluent	2.3	1.0	.7	.6	.7	.7	.6	.7	1.7	1.3	1.3	-	-
Final Effluent	1.6	.8	.6	.4	.6	.6	.5	.5	1.0	.5	.8	-	-
Soluble Phosphorus, mg/l:													
Raw Influent	5.0	4.7	5.9	5.0	2.8	4.7	2.8	3.4	3.4	3.4	3.3	-	4.1
Primary Effluent	4.8	1.4	1.5	1.1	1.5	1.2	1.1	1.0	3.3	2.5	2.7	-	-
Final Effluent	4.0	1.2	1.3	.8	1.0	1.0	.8	.7	1.7	.9	1.6	-	-
Suspended Phosphorus, mg/l:													
Raw Influent	2.6	2.4	2.3	2.3	2.3	2.4	2.4	1.0	3.0	3.2	3.0	-	2.4
Primary Effluent	2.8	1.6	1.2	.9	1.0	1.2	1.4	1.3	1.9	1.8	3.5	-	-
Final Effluent	1.3	.8	1.0	.8	.7	.8	.9	1.5	1.3	1.2	.7	-	-
Total Phosphorus, mg/l:													
Raw Influent	7.6	7.1	8.2	7.3	5.1	7.2	5.2	4.4	6.4	6.6	6.3	3.8	6.5
Primary Effluent	7.6	3.0	2.7	2.0	2.5	2.4	2.5	2.3	5.2	4.3	6.2	2.0	-
Final Effluent	5.3	2.0	2.3	1.6	1.7	1.8	1.7	2.2	3.0	2.1	2.3	.96	-
Total Phosphorus Loadings, lb/day:													
Raw Influent	2476.	2556.	1914.	2287.	1734.	2400.	1530.	1658.	2496.	2524.	2110.	1450.	2225.
Primary Effluent	2476.	1080.	630.	627.	850.	800.	735.	866.	2028.	1645.	2077.	772.	-
Final Effluent	1727.	720.	537.	501.	578.	600.	500.	829.	1170.	803.	770.	370.	-
Final Effluent, % of 1	100.	42.	31.	29.	33.	35.	29.	48.	68.	46.	45.	21.	-
Overall Removal	749.	1836.	1377.	1786.	1156.	1800.	1030.	839.	1326.	1721.	1340.	1080.	-

TABLE 7

MEAN VALUES FOR PHOSPHORUS RATIOS

	PERIOD												
	1	2A	2B	2C	2D	All 2	3	4	5A	5B	6	8	All (1-6)
Ortho/Total:													
Raw Influent	0.33	0.28	0.23	0.37	0.37	0.32	0.50	0.41	0.26	0.24	0.26	0.50	0.32
Primary Effluent	.33	.13	.28	.26	.32	.22	.20	.12	.31	.28	.23	.31	-
Final Effluent	.46	.22	.30	.25	.23	.26	.17	.09	.23	.21	.35	.33	-
Poly/Total:													
Raw Influent	.33	.38	.49	.31	.18	.34	.23	.36	.28	.28	.27	-	.31
Primary Effluent	.30	.33	.26	.28	.28	.28	.25	.32	.32	.30	.21	-	-
Final Effluent	.30	.40	.25	.25	.37	.31	.30	.23	.33	.22	.33	-	-
Soluble/Total:													
Raw Influent	.66	.66	.72	.68	.55	.66	.54	.77	.54	.52	.53	-	.63
Primary Effluent	.63	.47	.54	.54	.60	.50	.45	.44	.63	.58	.44	-	-
Final Effluent	.76	.62	.55	.50	.60	.57	.47	.32	.56	.43	.68	-	-
Suspended/Total:													
Raw Influent	.34	.34	.28	.32	.45	.34	.46	.23	.47	.48	.47	-	.37
Primary Effluent	.37	.53	.46	.46	.40	.50	.55	.56	.37	.42	.56	-	-
Final Effluent	.24	.38	.45	.50	.40	.43	.53	.68	.44	.57	.32	-	-

TABLE 8

MEAN VALUES FOR TREATMENT CHEMICALS AND COMPARATIVE CHEMICAL COSTS

	PERIOD										
	1	2A	2B	2C	2D	All 2	3	4	5A	5B	6	8
Ferric Iron, mg/l	-	16.5	20.7	20.0	11.1	18.3	19.0	20.2	10.0	20.0	15.0	18.2
Ferric/Raw Influent Total P, -	-	2.5	2.6	2.9	2.7	2.7	4.6	5.2	1.7	3.3	2.6	4.7
PURIFLOC A23 Flocculant, mg/l	-	.37	.31	.32	.32	.32	-	.33	-	-	.20	.28
Ferric Iron, lb/day	-	5940.	4830.	6267.	3774.	6100.	5589.	7609.	3900.	7650.	5025.	7022.
PURIFLOC A23 Flocculant, lb/day	-	133.	72.	100.	109.	107.	-	124.	-	-	67.	108.
Ferric Iron, $/MG	-	18.15	22.77	22.00	12.21	20.13	20.90	22.22	11.00	22.00	16.50	20.02
PURIFLOC A23 Flocculant, $/MG	-	2.62	2.20	2.27	2.27	2.27	-	2.34	-	-	1.42	1.98
Total Chemicals, $/MG	-	20.77	24.97	24.27	14.48	22.40	20.90	24.56	11.00	22.00	17.92	22.00
Ferric Iron, $/day	-	784.	638.	827.	498.	805.	738.	1004.	515.	1010.	663.	927.
PURIFLOC A23 Flocculant, $/day	-	113.	61.	85.	92.	91.	-	106.	-	-	57.	92.
Total Chemicals, $/day	-	897.	699.	912.	590.	896.	738.	1110.	515.	1010.	720.	1019.
Total Chemicals, $/lb P removed	-	.49	.50	.51	.51	.50	.72	1.34	.39	.59	.54	.94

TABLE 9

MEAN VALUES FOR FLOWS, OVERFLOW RATES, AND pH

	PERIOD												
	1	2A	2B	2C	2D	All 2	3	4	5A	5B	6	8	All (1-6)
Flow, mgd	39.1	43.2	28.0	37.6	40.8	40.0	35.3	45.2	46.8	45.9	40.2	46.3	41.1
Primary Overflow Rate, gpd/sq ft	855	1107	810	840	1123	956	1041	1071	1109	1089	1101	978	1025
Secondary Overflow Rate, gpd/sq ft	847	1067	1084	853	1040	958	899	1151	2981	2927	2203	1180	1518
pH, units													
Raw Influent	7.6	7.4	7.4	7.7	7.7	7.5	7.5	7.7	7.8	7.8	7.7	6.9	7.6
Primary Effluent	7.6	7.4	7.4	7.4	7.5	7.4	7.3	7.5	7.7	7.7	7.8	7.0	7.6
Final Effluent	7.6	7.4	7.3	7.3	7.4	7.4	7.3	7.4	7.8	7.8	7.3	7.0	7.5

TABLE 10

MEAN VALUES FOR
BIOCHEMICAL OXYGEN DEMAND AND SUSPENDED SOLIDS CONCENTRATIONS AND LOADINGS

	PERIOD												
	1	2A	2B	2C	2D	All 2	3	4	5A	5B	6	8	All (1-6)
Biochemical Oxygen Demand (5-day), mg/l:													
Raw Influent	111	101	111	110	104	106	105	98	134	118	124	100	111
Primary Effluent	89	51	64	57	48	55	78	52	90	74	106	61	-
Final Effluent	24	18	22	24	23	22	37	53	24	25	17	29	-
Suspended Solids, mg/l:													
Raw Influent	139	112	124	130	113	122	139	86	167	144	129	126	128
Primary Effluent	112	43	50	44	43	44	94	54	97	73	120	86	-
Final Effluent	40	21	30	27	21	24	40	80	37	30	16	44	-
Organic Loading, 1000 lb/day:													
Raw Influent	36.2	36.3	25.9	34.5	35.3	35.3	30.9	36.9	52.2	45.1	41.5	38.6	38.0
Primary Effluent	29.0	18.4	14.9	17.9	16.3	18.3	22.9	19.6	35.1	28.3	35.5	23.5	-
Final Effluent	8.2	6.5	5.1	7.5	7.8	7.3	10.9	20.0	9.4	9.6	5.7	11.2	-
Solids Loading, 1000 lb/day:													
Raw Influent	45.3	40.3	28.9	40.7	38.4	40.7	40.9	32.4	65.1	55.1	43.2	48.6	43.8
Primary Effluent	36.5	15.5	11.7	13.8	14.6	14.7	27.6	20.3	37.8	27.9	40.2	33.2	-
Final Effluent	13.7	7.6	7.0	8.5	7.2	8.0	11.8	30.1	14.4	11.5	5.4	17.0	-

TABLE 11

MEAN VALUES FOR HEAVY METALS

	PERIOD												
	1	2A	2B	2C	2D	All 2	3	4	5A	5B	6	8	All (1-6)
Chromium, mg/l:													
Raw Influent	2.0	1.5	1.3	1.0	0.8	1.2	0.8	0.5	0.8	0.8	1.2	1.2	1.1
Primary Effluent	1.8	.9	.7	.4	.5	.6	.5	.4	.6	.5	.8	.8	-
Final Effluent	1.0	.3	.3	.3	.3	.3	.3	.3	.3	.3	.2	.4	-
Copper, mg/l:													
Raw Influent	1.0	.8	1.0	.8	.6	.8	.5	.4	.5	.4	.4	.4	.7
Primary Effluent	.9	.5	.6	.4	.3	.4	.4	.3	.3	.3	.4	.5	-
Final Effluent	.8	.6	.6	.2	.2	.4	.2	.2	.2	.2	.2	.3	-
Iron, mg/l:													
Raw Influent	2.4	1.6	2.7	2.6	1.7	2.2	1.8	1.5	2.7	4.6	3.6	1.5	2.5
Primary Effluent	2.1	2.1	2.7	3.2	4.6	2.9	6.3	1.8	1.9	2.0	3.4	4.7	-
Final Effluent	.9	1.1	1.1	2.5	2.0	1.9	3.0	6.1	1.9	2.4	1.1	4.3	-
Nickel, mg/l:													
Raw Influent	1.8	1.6	1.5	1.2	.8	1.3	.8	.5	.7	.5	.8	.6	1.1
Primary Effluent	1.7	1.3	1.1	.7	.6	1.0	.7	.4	.5	.4	.7	.7	-
Final Effluent	1.6	1.2	1.0	.6	.3	.9	.6	.3	.4	.3	.4	.6	-
Zinc, mg/l:													
Raw Influent	2.0	1.6	2.0	3.9	2.2	2.8	4.2	1.3	4.0	3.7	3.7	1.8	2.9
Primary Effluent	2.0	.8	1.3	1.4	1.3	1.2	2.2	1.2	2.8	2.9	3.0	2.7	-
Final Effluent	1.1	.6	1.0	1.1	1.0	.9	1.4	1.5	2.2	2.1	1.3	1.9	-

SECTION VIII

DISCUSSION OF RESULTS BY PERIOD

The results obtained during the eight basic periods listed in Table 5 are discussed in two ways. Features peculiar to each period, and to each mode of chemical treatment as depicted in Figure 6, are emphasized in the first discussion in numerical order according to period. Reference is made to individual mean values previously tabulated. An occasional comparison is made between a mean influent value for a selected period and the corresponding collective mean for Periods 1-6. The significance of each individual parameter is described in the second discussion appearing in the subsequent section of this report (See the section entitled Discussion of Individual Parameters).

Period 1 - No Chemical Treatment (Days 182-546)

The 1969-1970 fiscal year of operation was used as the control period. This period of one year provides comparative values for all parameters in the absence of chemical treatment. Daily analyses for one full year were available for all of the parameters except soluble BOD and COD which are 3-month averages. A summary of values for those parameters is provided in Table 12. Most values were reported previously[14]. Mean values in parentheses ( ) were determined by computer techniques for comparison. No data from this period were discarded for those parameters subjected to statistical analysis since the total numbers were very large.

The following points are emphasized for Period 1.

a. The mean raw influent analyses were all comparable to the collective means for six periods (See Tables 6-10) with the exception of a higher chromium concentration (2.0 vs 1.1 mg/l) (See Table 11).

Figure 6 – **MODES OF CHEMICAL ADDITION**

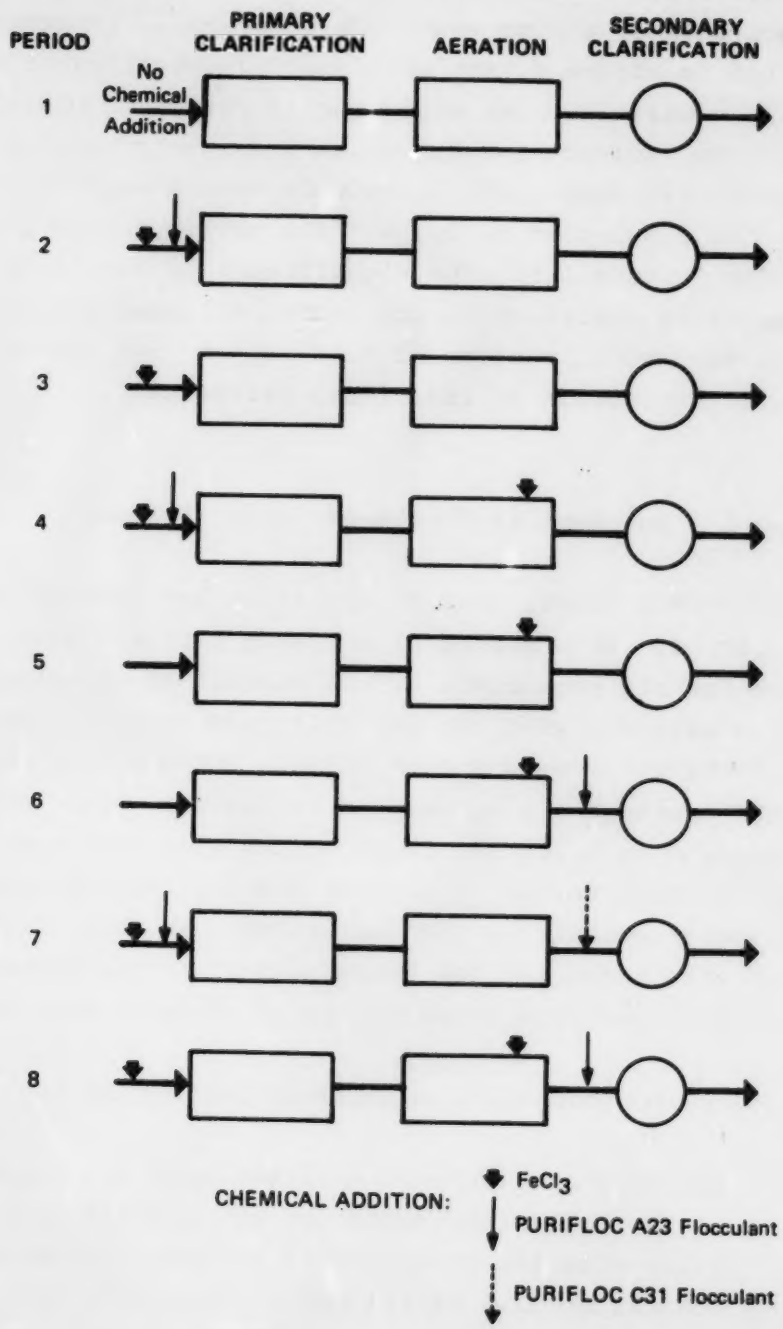


TABLE 12

SUMMARY OF OPERATION IN ABSENCE OF CHEMICAL TREATMENT

(Period 1: Days 182-546 Inclusive)

Parameter	Concentration, mg/l (except as noted) Raw Influent	Primary Effluent	Final Effluent
Ortho-Phosphorus, as P	2.5 (2.5)	2.5	2.5
Poly Phosphorus, as P	2.5 (2.5)	2.2	1.6
Soluble Phosphorus, as P	4.9 (5.0)	4.7	4.1
Suspended Phosphorus, as P	- (2.6)	-	-
Total Phosphorus, as P	7.7 (7.6)	7.6	5.4
Biochemical Oxygen Demand (5-day)	111 (111)	89	26
Soluble BOD (5-day)	49	41	16
Chemical Oxygen Demand	308	238	103
Soluble COD	109	107	73
Suspended Solids	139 (139)	112	43
Volatile Suspended Solids	109	85	36
Total Solids	828	812	695
Chromium	2.4 (2.0)	2.5	1.6
Copper	1.3 (1.0)	1.2	1.1
Iron	4.1 (2.4)	4.1	1.4
Nickel	2.0 (1.8)	1.8	1.6
Zinc	3.4 (2.0)	2.9	1.8
Cyanide	1.0	0.9	0.6
Ammonia Nitrogen, as N	9.6	10.1	10.2
Total Nitrogen, as N	10.7	13.0	11.7
Nitrate Nitrogen, as N	-	-	0.52
Alkalinity, as $CaCO_3$	225	238	223
Chloride	163	176	165
Grease and Oil	110	87	22
pH, Units	7.6	7.6	7.6
Turbidity, JTU	-	-	90
Total Coliform, no./100 ml	-	-	2,218
Fecal Coliform Group, no./100 ml	-	-	385
Fecal Streptococcal Group, no./100 ml	-	-	1,832
Flow mgd	39.7(39.1)		

b. The raw influent and primary effluent each contained about equal amounts (See Table 6) and equal ratios (See Table 7) of ortho, poly, and suspended phosphorus (each species one-third of total).
c. The concentrations of the soluble phosphorus species were relatively unchanged during primary or secondary treatment (See Table 6).
d. The overall removal of total phosphorus of about 30 percent (7.6 vs 5.3 mg/l) was due mainly to the capture of suspended phosphorus since little insolubilization of other species occurred (See Tables 6 and 14).
e. Primary and overall removals of biochemical oxygen demand were 20 percent and 78 percent, respectively (See Tables 10 and 15).
f. Primary and overall removals of suspended solids were 20 percent and 71 percent, respectively (See Tables 10 and 15).
g. Primary removals of all metals were negligible (<20 percent); overall removals of chromium, iron, and zinc were approximately 50-60 percent; overall removals of copper and nickel were also negligible (<20 percent) (See Tables 11 and 16).

Period 2 - Metal + Flocculant Addition to Primary
(Days 672-786, 860-874, 888-1023, 1080-1093)

Addition points for the two chemicals during this period had been established during the feasibility study. Ferric chloride was applied at Point A. The flocculant was applied most effectively at Point H_1-H_8. Other points of addition listed in Table 2 were less satisfactory.

This large period was subdivided during operation into four subperiods of varying lengths spread throughout all seasons.

The following points are emphasized for Period 2.

a. Mean raw influent values for all parameters except chemical additions for the entire period were comparable to the collective means for six periods (See Tables 6-11).
b. Raw influent poly phosphorus concentrations for the short subperiods 2B and 2D were somewhat atypical compared to Period 1 (4.0 and 0.9 vs 2.5 mg/l, respectively) (See Table 6).
c. The mean soluble phosphorus concentration in the final effluent was 1.0 mg/l after precipitation; suspended phosphorus was reduced to an average of 0.8 mg/l (See Table 6).
d. Additional ferric chloride and better liquid-solids separation is required to reduce the soluble phosphorus level and the suspended phosphorus level to the point where a mean final effluent level of 1.0 mg/l total phosphorus can be achieved (See Table 6).
e. Primary removal of biochemical oxygen demand was increased by chemical treatment (48 vs 20 percent); overall removal remained essentially the same as that obtained during the control period (79 vs 78 percent) (See Tables 10 and 15).
f. Primary removal of suspended solids was significantly improved by chemical treatment (64 vs 19 percent); overall removal was also somewhat improved (80 vs 71 percent) (See Tables 10 and 15).
g. Removals of chromium, copper, and zinc were dramatically increased, particularly during primary treatment (>50 vs <10 percent). Removal of nickel was improved but less dramatically (See Tables 11 and 16).

h. Although the degree of iron removal was reduced, there was no net increase in iron concentration in the final effluent as a result of chemical treatment (1.9 vs 2.2 mg/l) (See Tables 11 and 16).

i. The total phosphorus content of the primary sludge was increased by about one-third (43 vs 33 mg/g); the total iron content of this sludge was increased almost four-fold (8.6% vs 2.2%) (See Table 18).

j. The total phosphorus content of the waste activated sludge also was increased by about one-third (65 vs 50 mg/g); the total iron content of this sludge was increased slightly less than three-fold (76 vs 28 mg/g) (See Table 18).

k. The primary sludge during chemical treatment was higher in solids content than during the period of no chemical treatment. Its specific resistance to filtration (7) was reduced a factor of three-fold (7.9 vs 2.43 m/kg,) (See Table 19).

Period 3 - Metal Addition Only to Primary (Days 1024-1073)

The point of ferric chloride application remained unchanged at Point A. The reduced effectiveness of ferric chloride when used in absence of a flocculant was demonstrated during this period when the iron concentration in the primary effluent increased. Unfortunately, the raw influent sampler was inoperative during a major portion of this period and the apparently high ratio of added iron/raw influent total phosphorus is based upon data from 20% of the period.

The following points are emphasized for Period 3.

a. Raw influent values of ortho phosphorus, flow, biochemical oxygen demand, and suspended solids were in surprisingly close agreement to those of the control period considering the lack of a large number of samples. Raw influent values of all metals except zinc were similar to the collective means of six periods (See Tables 6-11).

b. The mean soluble phosphorus concentration in the final effluent was reduced to less than 1.0 mg/l, but the raw influent concentration was also the lowest of all periods studied (2.8 vs 4.1 mg/l) (See Table 6).

c. Overall removal of total phosphorus was somewhat less than Period 2 on a percentage basis (67 vs 75 percent) but comparable on an absolute concentration basis (1.7 vs 1.8 mg/l) (See Tables 6 and 14). The absence of flocculant, however, was inadvertently compensated in part by an apparently much higher added iron/raw influent total phosphorus ratio (4.6 vs 3.1) (See Table 8) during this period than for almost all of the other periods.

d. Removals of biochemical oxygen demand were not improved over those of the control (See Tables 10 and 15).

e. Removals of suspended solids were not improved over that of the control (See Tables 10 and 15).

f. Removals of all metals except iron were comparable to Period 2 (See Tables 11 and 16).

g. Substantial net increases in iron concentrations in both primary (250 percent) and final (167 percent) effluents were observed. These are compared to overall net decreases during the control Period 1 (62 percent), and also during Period 2 (14 percent) when a flocculant was added (See Table 16).

h. The concentrations of chromium, copper, and nickel in the raw influent were reduced in Period 3 and subsequent periods when pretreatment practices were initiated by local industries.

Period 4 - Split Addition of Metal to Both Primary and Secondary + Flocculant Only to Primary (Days 1074-1079)

During this period, approximately 10 mg/l of iron were added at Point A, and an additional 10 mg/l added at Points L_1-L_6. This was accomplished by setting up a ferric chloride storage tank, variable speed pump, and proportioning weir box at the downstream end of the aeration tanks. It was a logistic problem at that time to add flocculant following aeration, and it was added only before primary clarification at Points G_1-G_2.

This period was extremely short and although trends can be noted, the absolute concentration values are not as statistically reliable as the other periods of this study. The split mode of treatment did merit further study as described for Period 8. The preferable approach is the addition of ferric chloride to both primary and secondary. The flocculant then should be added shortly thereafter near the sites of both metal additions, or at least after the second rather than only after the first metal addition.

The following points are emphasized for Period 4.

a. Several of the raw influent values were lower than those of six other periods. These include: suspended and total phosphorus, biochemical oxygen demand, suspended solids, and all of the metals (See Tables 6-11).

b. Soluble phosphorus in the final effluent was reduced to less than 1.0 mg/l but suspended phosphorus was not adequately captured to assure a total phosphorus concentration of less than 1.0 mg/l (See Table 6).

c. The suspended phosphorus ratio remaining in the final effluent was the largest of all of the periods of chemical treatment (0.68). This ratio was reduced when the flocculant was added after the second addition of ferric chloride prior to secondary clarification during Period 8 (See Table 7).

d. The biochemical oxygen demand in the primary effluent was comparable to Period 2 (52 vs 55 mg/l); no further reduction of biochemical oxygen demand occurred during secondary treatment (53 mg/l) and was probably due to the relatively high concentration of suspended solids in the final effluent (See Table 10).

e. The primary effluent concentrations of suspended solids was somewhat less than Period 2 (54 vs 44 mg/l); the final effluent concentration was high (80 mg/l) (See Table 10).

f. Final effluent concentrations of all metals except iron and zinc were comparable to Period 2 (See Table 11), even though the percentages of removal were less because of lower raw influent concentrations (See Table 16).

g. The slight increase in the iron concentration of the primary effluent was comparable to that observed in Period 2. The large increase in the iron concentration of the final effluent compared to the raw influent (6.1 vs 1.5 mg/l), however, was exceeded only by the increase observed in the primary effluent of Period 3 (6.3 vs 1.8 mg/l) also obtained in the absence of a flocculant addition after an iron addition (See Table 11).

Period 5 - Metal Addition Only to Secondary (Days 1198-1225)

Ferric chloride was added at Points L_1-L_6. Even distribution of ferric chloride was obtained to all tanks from one line running from the storage tanks. To add iron at any other points of aeration, such as midway or one-third distance, would have required the construction of a temporary header causing a safety and maintenance problem.

This period was subdivided into two subperiods. The effects of doubling the concentration of iron are illustrated when comparing Periods 5A and 5B. The removal of certain components in the waste were greatly influenced by very high secondary overflow rates during these periods [1306 cu m/day-sq m and 1283 cu m/day-sq m (2981 and 2927 gal/day/sq ft)], respectively for Periods 5A and 5B.

The following points are emphasized for Periods 5A and 5B.

a. Raw influent values for all parameters for both Periods 5A and 5B were comparable to the collective means of six periods with the exception of a high mean iron concentration for Period 5B (4.6 vs 2.5 mg/l) (See Tables 6-11).
b. The mean secondary overflow rate for both subperiods was approximately three times that of all of the other periods [1306 cu m/day-sq m and 1283 cu m/day-sq m vs 385 cu m/day-sq m (2981 and 2927 vs approx. 1000 gpd/sq ft)] (See Table 9).
c. The soluble phosphorus level in the final effluent for Period 5A was higher than for Period 5B (1.7 vs 0.9 mg/l) (See Table 6) because of the lower concentration of ferric iron added (10 vs 20 mg/l) (See Table 8).

d. Suspended phosphorus and consequently total phosphorus removals suffered somewhat because of the high secondary overflow rates. The suspended phosphorus level in the final effluent of Period 5B after metal addition, however, was only slightly less than that of Period 2 (1.2 vs 0.8 mg/l) (See Tables 6 and 14).

e. Overall removal of biochemical oxygen demand (79 percent, 25 mg/l) was comparable to the control period (78 percent, 24 mg/l) and to Period 2 (79 percent, 22 mg/l); primary removal (37 percent, 74 mg/l) was greater than the control (20 percent, 89 mg/l) but less than Period 2 (48 percent, 55 mg/l) (See Tables 10 and 15).

f. Overall removal of suspended solids was comparable to Period 2 on a percentage basis (79 vs 80 percent) (See Table 15), but less on an absolute concentration basis (30 vs 24 mg/l) (See Table 10); primary removal was somewhat better than the control (73 vs 112 mg/l) but definitely less than Period 2 (73 vs 44 mg/l) (See Table 10).

g. The removals of all metals except zinc were comparable to Period 2 (See Tables 11 and 16). The mean zinc concentration in the final effluent (2.1 mg/l) was the highest of all periods (See Table 11).

Period 6 - Metal + Flocculant Addition to Secondary (Days 1226-1250)

The ferric chloride feeding system remained unchanged at Points L_1-L_6. The flocculant was added with a pump manually adjusted proportional to the wastewater flow. The flocculant was pumped to a constant head splitting box where it was distributed equally to all entrances to the final

sedimentation tanks at Points M_1-M_6. This period of chemical treatment was also characterized by very high secondary overflow rates averaging 847 cu m/day-sq m (2203 gal/day/sq ft).

The following points are emphasized for Period 6.

a. The mean raw influent values for all parameters except secondary overflow rate were comparable to the collective means of six periods (See Tables 6-11).
b. Soluble phosphorus was not insolubilized to the extent of Period 2 (1.6 vs 1.0 mg/l) (See Table 6), probably because of a somewhat reduced ferric iron concentration (15.0 vs 18.3 mg/l) (See Table 8).
c. The suspended phosphorus concentration in the final effluent (0.7 mg/l) was the lowest of six periods (See Table 6).
d. Primary removal of biochemical oxygen demand was comparable to the control period (See Table 15); the final effluent concentration (17 mg/l) was the lowest of six periods and slightly better than Period 2 (22 mg/l) (See Table 10).
e. Primary removal of suspended solids was comparable to the control (See Table 15); the final effluent concentration of suspended solids (16 mg/l) was the lowest of all periods (See Table 10).
f. There was a considerable increase in the amount of waste activated sludge produced compared to Period 1 (See Table 17).
g. The phosphorus and iron concentrations of the waste activated sludge were both tripled (144 mg P/g and 87 mg Fe/g) over those concentrations obtained in the absence of chemical treatment (50 mg P/g and 28 mg Fe/g) (See Table 18).

Period 7 - Metal & Anionic Flocculant Addition to Primary + Cationic Flocculant Addition to Secondary (Days 982-986)

A cationic polyelectrolyte, PURIFLOC C31 flocculant, was added at a concentration of 41 mg/l to the influent to No. 6 secondary clarifier to determine if improved capture of suspended solids and suspended phosphorus was possible. This concentration is considered excessive and not economical. This period was concurrent with Period 2C. Samples from No. 6 (treated) and No. 5 (untreated) secondary clarifiers were analyzed for suspended solids, volatile suspended solids, biochemical oxygen demand, and total phosphorus. Average values were not significantly different between the treated and untreated clarifiers. The total phosphorus concentrations averaged about 1 mg/l for both samples. A thick scum layer did form on top of the treated clarifier and collection of representative samples was difficult. This scum contained 600 mg/l grease and oil compared to only 39 mg/l for the underlying clear liquid. An average of 68 mg/l grease and oil in the final effluent was determined for the untreated clarifier during this period.

Period 8 - Split Addition of Metal to Both Primary and Secondary + Flocculant Only to Secondary (Days 1462-1520)

The data of this supplemental period are included to demonstrate the effectiveness of chemical treatment when the flow was slightly above design, operating conditions were near normal, all existing units were in service, and there were no disruptions from construction of new facilities. One exception was the periodic bypassing of that portion of the primary effluent ($\sim$10 percent) exceeding the design

flow of 167,000 cu m/day (44 mgd) into the final effluent without benefit of secondary treatment. The overall effectiveness of chemical treatment was probably not optimum due to bypassing. The mean concentrations of ferric iron were 18.2 mg/l split approximately equally in quantity between Point A and Points J_1-J_6. The mean concentration of flocculant was 0.28 mg/l added at Points L_1-L_6. Results from Period 8 are summarized in Table 13.

The following points are emphasized for Period 8.

a. The mean raw influent concentration of ortho phosphorus was comparable to the collective mean of 6 other periods (1.8 vs 2.1 mg/l) (See Table 6).
b. The mean raw influent concentration of total phosphorus was lower than the collective mean of 6 other periods (3.8 vs 6.5 mg/l) (See Table 6).
c. The mean ortho phosphorus concentration in the final effluent (0.2 mg/l) was lower than any period except Period 4 (See Table 6).
d. The mean total phosphorus concentration in the final effluent (0.96 mg/l) was the lowest of all periods and met the desired criterion of $\leq$1 mg/l (See Table 6).
e. Efficiencies of removal of both ortho (89 percent) and total phosphorus (75 percent) were comparable to the best of all other periods (See Table 14).
f. Overall removal of suspended solids (65 percent) was lower than most of the other periods of chemical treatment due to periodic bypassing of primary effluent into the final effluent (See Table 15).
g. Overall removal of biochemical oxygen demand (71 percent) was comparable to most of the other periods (See Table 15).

TABLE 13

SUMMARY OF OPERATION DURING SUPPLEMENTAL PERIOD

(Period 8: Days 1462-1520 Inclusive)

Parameter	Concentration, mg/l (except as noted) Raw Influent	Primary Effluent	Final Effluent
Ortho-Phosphorus, as P	1.83	0.60	0.20
Total Phosphorus, as P	3.85	2.01	0.96
Biochemical Oxygen Demand	100.	61.	29.
Suspended Solids	126.	86.	44.
Chromium	1.16	0.79	0.44
Copper	0.38	0.46	0.34
Iron	1.54	4.66	4.29
Nickel	0.63	0.69	0.56
Zinc	1.77	2.66	1.92
pH, units	6.9	7.0	7.0
Flow, mgd	46.3	-	-
Ferric Iron (to both primary and secondary)		9.1	9.1
PURIFLOC A23 flocculant (only to secondary)		-	0.28

h. Final effluent concentrations of chromium, copper, nickel, and zinc were comparable to most of the other periods (See Table 11).

i. The high mean iron concentration in the primary effluent (4.7 gm/l) was attributed to poor solids capture in the absense of flocculant. The high mean concentration of iron in the final effluent (4.3 mg/l) was attributed to periodic bypassing of a portion of the primary effluent (See Table 11).

SECTION IX

DISCUSSION OF INDIVIDUAL PARAMETERS

The independent variables of ferric iron concentration, polyelectrolyte flocculant concentration, and clarifier overflow rates have pronounced effects on the various dependent variables indicative of treatment performance. The responses of these individual dependent variables such as phosphorus, biochemical oxygen demand, suspended solids, heavy metals, and other treatment parameters are discussed in this section.

Phosphorus

The shifting ratios of the three major phosphorus species, ortho, poly, and suspended, expressed as fractions of the total phosphorus, were summarized previously in Table 7. The three fractions, ortho/total, poly/total, and suspended/total, at any given plant location all add up to a value of unity or 100 percent of the total. Initially in the raw influent the three fractions are about equal. Upon addition of the ferric chloride, both ortho and poly phosphorus fractions decrease due to insolubilization and the suspended fraction increases. Upon addition of PURIFLOC A23 flocculant, the suspended fraction is decreased by flocculation and sedimentation and the ortho and poly fractions are increased. The concentration of total phosphorus in the wastewater decreases progressively through primary and secondary treatment as solids settle and are removed from the system.

A comparison of phosphorus removal efficiencies for the major periods is provided in Table 14. Conversion of ortho phosphorus to an insoluble form was 75-90 percent complete except for Period 6. The mean concentration of ferric iron

TABLE 14

COMPARISON OF REMOVAL EFFICIENCIES FOR VARIOUS PHOSPHORUS SPECIES

(Locations: PE = Primary Effluent, FE = Final Effluent)

Chemicals	Location	Period 1	2	3	4	5B	6	8
		Concentrations, mg/l						
Ferric Iron	Primary	0	18.3	19.0	10.0	0	0	9.1
	Secondary	0	0	0	10.0	20.0	15.0	9.1
PURIFLOC A23 Flocculant	Primary	0	0.32	0	0.33	0	0	0
	Secondary	0	0	0	0	0	0.20	0.28
Phosphorus Species		Removal Efficiencies, % (cumulative)						
Ortho	PE	0	78.	81.	83.	25.	12.	67.
	FE	4.	78.	88.	89.	75.	50.	89.
Poly	PE	8.	71.	50.	56.	28.	24.	-
	FE	36.	75.	58.	69.	72.	53.	-
Soluble	PE	4.	74.	61.	71.	26.	18.	-
	FE	20.	79.	71.	79.	74.	52.	-
Suspended	PE	0	50.	42.	0	44.	0	-
	FE	50.	67.	62.	0	62.	77.	-
Total	PE	0	67.	52.	48.	35.	2.	49.
	FE	30.	75.	67.	50.	68.	63.	75.

added during Period 6, however, was about 25 percent less than those of the other periods. Conversion of poly phosphorus to an insoluble form was somewhat less efficient than the conversion of ortho phosphorus. With the exception of Period 6, the conversion of soluble phosphorus (ortho and poly phosphorus) was 70-80 percent complete.

The major limitation to removal of total phosphorus was not the conversion of soluble phosphorus to an insoluble form but rather the capture of the suspended phosphorus. This latter species consists of two fractions. One fraction is comprised of suspended phosphorus originally present in the raw influent, probably as inorganic solids or insoluble organic phosphorus. The second fraction of suspended phosphorus is comprised of newly precipitated iron phosphates. At the Grand Rapids plant it was necessary to add an anionic flocculant to flocculate the suspended phosphorus from either source and thereby enhance sedimentation.

The frequencies of occurrence of ortho phosphorus in the raw influent, primary effluent and final effluent during Period 8 are shown in Figure 7. The mean ortho phosphorus concentration in the final effluent was the lowest of all other periods except Period 4 for which the same mean concentration was observed. Split additions of comparable amounts of ferric iron were made in both Period 4 and Period 8. Insolubilizations of ortho and poly phosphorus, therefore, were expected to be comparable.

The frequencies of occurrence of total phosphorus during Period 8 in various plant locations are shown in Figure 8. The mean total phosphorus concentration in the final effluent during Period 8 was 0.96 mg/l. This concentration met the desired goal of this study of 1 mg/l. Period 8 was the only period of study in which ferric chloride was

Figure 7 – FREQUENCIES OF OCCURRENCE OF ORTHO PHOSPHORUS DURING PERIOD 8

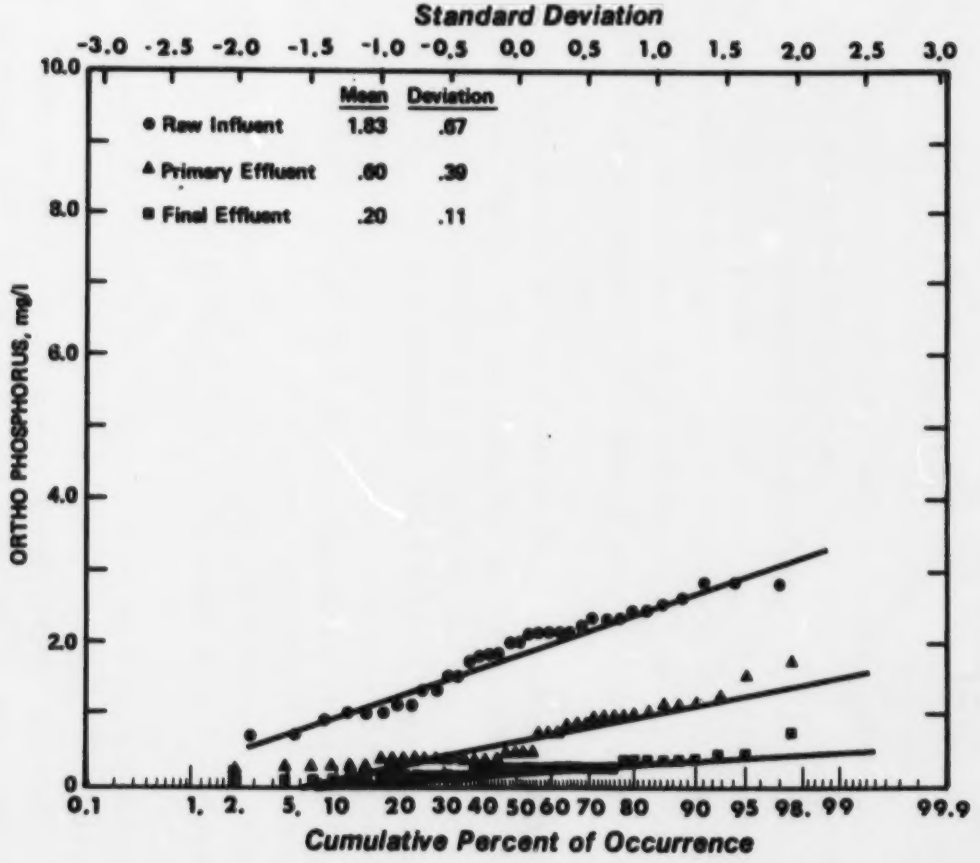
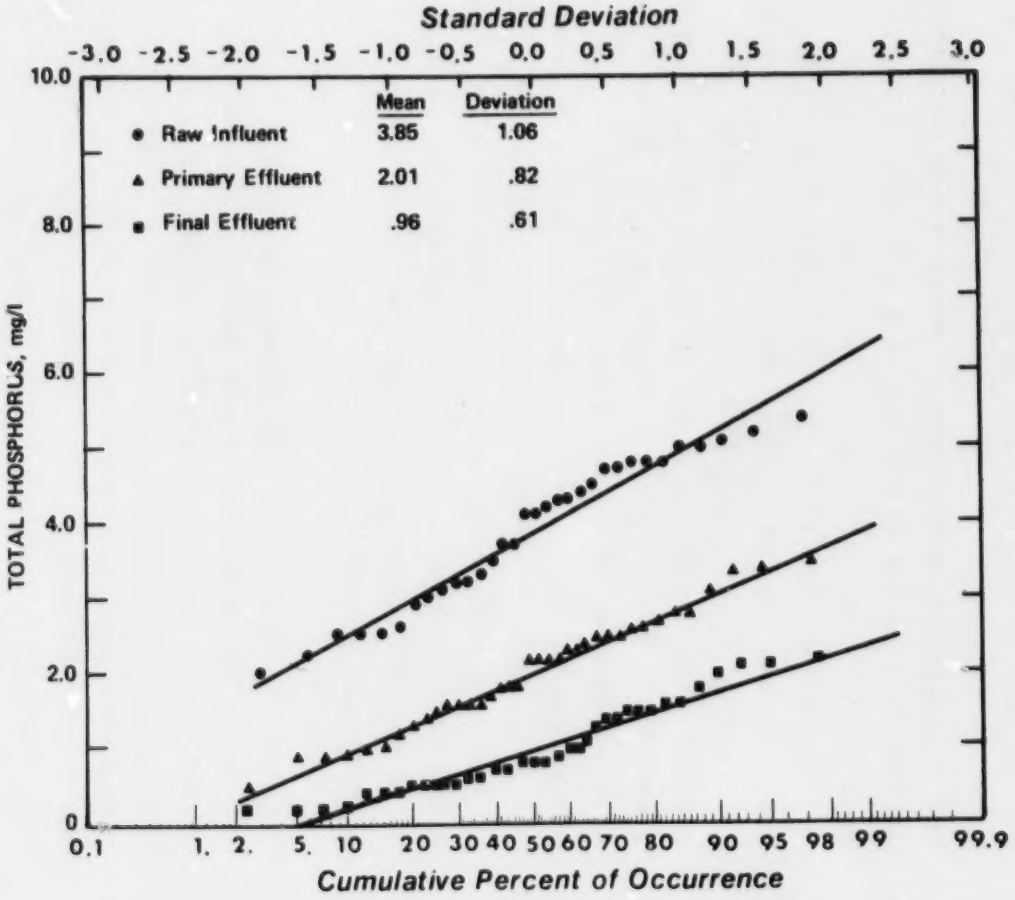


Figure 8 – FREQUENCIES OF OCCURRENCE OF TOTAL PHOSPHORUS DURING PERIOD 8

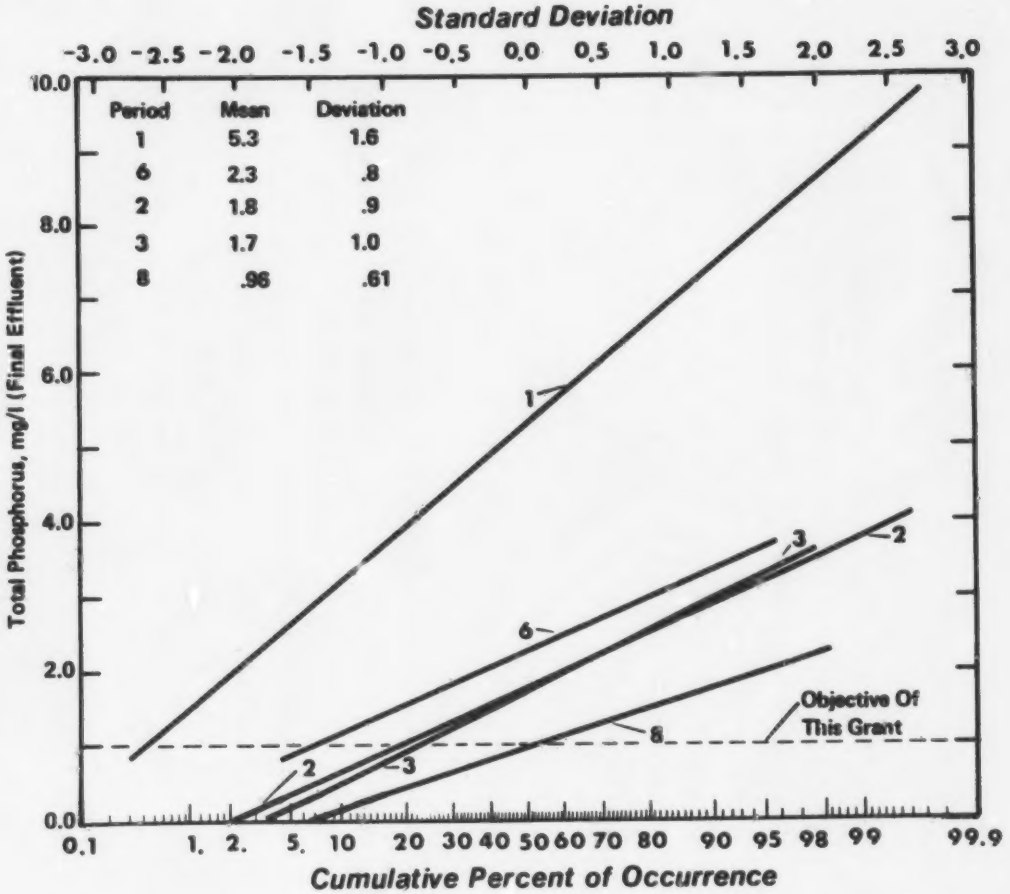


added during both primary and secondary treatment and PURIFLOC A23 flocculant was added only to secondary. The reduced efficiency of removal of total phosphorus during primary treatment during Period 8 is attributed directly to inadequate flocculation (no flocculant). The overall removal of total phosphorus during Period 8 is somewhat less than optimum due to some primary effluent bypassing secondary treatment. Split addition of both chemicals is recommended for optimum phosphorus removal at the Grand Rapids plant.

The frequencies of occurrence of the total phosphorus concentrations in the final effluent for several selected Periods 1, 2, 3, 6, and 8 are shown in Figure 9. Similar data collected for Periods 4, 5, and 7 were limited in number and were not included. The relative efficiencies of overall removals of total phosphorus can be compared for the various periods when operating under different modes of chemical treatment. The mean values previously included in Table 6 were represented as 50 percent occurrences, i.e., a given concentration is expected to be equal to or greater than the mean value 50 percent of all occurrences and equal to or less than the mean value 50 percent of all occurrences. A concentration of $\leq$1 mg/l total phosphorus is expected to occur $\leq$0.35 percent for the control Period 1 but $\geq$50 percent for Period 8.

The mean loadings of total phosphorus (Table 6) entering the secondary treatment stage and/or the receiving stream (Grand River) are significantly reduced by chemical treatment prior to primary and/or secondary treatment. The total phosphorus load to the Grand River during the control Period 1 was 782 kg/day (1727 lb/day). This agrees well with the value of 739 kg/day (1632 lb/day) calculated on the basis of an average river flow of 85.8 cu m/sec (3032 cu ft/sec) and average total phosphorus concentrations in the

Figure 9 – FREQUENCIES OF OCCURRENCES FOR FINAL EFFLUENT TOTAL PHOSPHORUS CONCENTRATIONS FOR SELECTED PERIODS



river of 0.16 and 0.26 mg/l, respectively, above and below the plant outfall. During chemical treatment the load of total phosphorus to the river decreased four-fold to as low as 168 kg/day (370 lb/day)(Period 8).

Biochemical Oxygen Demand and Suspended Solids

The removal efficiences of BOD (5-day) and suspended solids for several major periods are provided in Table 15. Removal of BOD during primary treatment was improved if both ferric chloride and the anionic flocculant were added prior to primary sedimentation. This was illustrated by the results for Periods 2 and 4. The removals of BOD during primary treatment for Periods 3 and 6 were not appreciably different from those obtained during the control Period 1 since no flocculant was added in primary treatment during either period. Overall removals of BOD were not improved by chemical treatment except in Period 6, which was the only period in which all of the required iron and the flocculant were added during secondary treatment.

Removals of suspended solids were improved if at least 15 mg/l of ferric iron were added and followed by PURIFLOC A23 flocculant. This was evident during primary treatment during Period 2 compared to Period 3, and during secondary treatment during Period 6 compared to Period 5B. The removals of suspended solids and suspended phosphorus can be equated to a first approximation. Any reduced efficiency of removal of suspended solids also resulted in reduced removal of suspended phosphorus.

The organic and solids loadings (Table 10) at various locations in the plant can be significantly influenced by chemical treatment. The effects of recycled suspended solids

TABLE 15

COMPARISON OF REMOVAL EFFICIENCIES FOR
BIOCHEMICAL OXYGEN DEMAND AND SUSPENDED SOLIDS

(Locations: PE = Primary Effluent, FE = Final Effluent)

		Period						
		1	2	3	4	5B	6	8
Chemicals	Location	Concentrations, mg/l						
Ferric Iron	Primary	0	18.3	19.0	10.0	0	0	9.1
	Secondary	0	0	0	10.0	20.0	15.0	9.1
PURIFLOC A23 Flocculant	Primary	0	0.32	0	0.33	0	0	0
	Secondary	0	0	0	0	0	0.20	0.28
Component Removed		Removal Efficiencies, % (cumulative)						
BOD (5-day)	PE	20.	48.	26.	47.	37.	15.	39.
	FE	78.	79.	65.	46.	79.	86.	71.
Suspended Solids	PE	19.	64.	32.	37.	49.	7.	32.
	FE	71.	80.	71.	7.	79.	88.	65.

and biochemical oxygen demand and the formation of chemically precipitated solids ahead of primary treatment are not included in the raw influent loadings but are by necessity included in the primary effluent loading to secondary treatment and the final effluent loading to the receiving stream. Net decreases in both organic and solids loadings are evident after primary treatment (Periods 2, 3 and 4) and secondary treatment (Periods 2 and 6).

Heavy Metals

A comparison of the percentages of removal of iron and four other metallic species is provided in Table 16. Increased removals of chromium and zinc paralleled the increased removals of suspended solids when both ferric chloride and the polyelectrolyte flocculant were added. The removals of copper and nickel were not as dramatically affected by chemical treatment. Gradually decreasing concentrations of the various metals in the raw influent were measured as the study progressed. These decreases were probably the result of operation of new pretreatment facilities by all of the larger metal-plating plants in the Grand Rapids area. The removals of chromium, copper, nickel, and zinc during the control Period 1 were comparable to those reported in the absence of chemical treatment.

Iron

Addition of soluble iron salts to wastewater usually does not result in increased iron concentrations in the final effluent if an aerobic process is utilized. The addition of an anionic flocculant after iron addition and reaction was found to be necessary at the Grand Rapids plant to agglomerate any fine iron-phosphate flocs that did not settle readily in the hydraulically overloaded secondary clarifiers.

TABLE 16

COMPARISON OF REMOVAL EFFICIENCIES OF VARIOUS HEAVY METALS

(Locations: PE = Primary Effluent, FE = Final Effluent)

		Period						
		1	2	3	4	5B	6	8
Chemicals	Location	Concentrations, mg/l						
Ferric Iron	Primary	0	18.3	19.0	10.0	0	0	9.1
	Secondary	0	0	0	10.0	20.0	15.0	9.1
PURIFLOC A23 Flocculant	Primary	0	0.32	0	0.33	0	0	0
	Secondary	0	0	0	0	0	0.20	0.28
Metal Species		Removal Efficiencies, % (cumulative)						
Chromium	PE	10.	50.	38.	20.	38.	33.	32.
	FE	50.	75.	62.	40.	62.	83.	62.
Copper	PE	10.	50.	20.	25.	25.	0	-21.
	FE	20.	50.	60.	50.	50.	50.	11.
Iron	PE	12.	-32.	-250.	-120.	57.	6.	-203.
	FE	62.	14.	-167.	-407.	48.	69.	-179.
Nickel	PE	6.	23.	12.	29.	20.	12.	-10.
	FE	11.	31.	25.	43.	40.	50.	11.
Zinc	PE	0	57.	48.	30.	22.	19.	-50.
	FE	55.	68.	67.	45.	43.	65.	-8.

No net increases in iron concentration were observed in the present study except in those cases where no flocculant was added after an iron addition; e.g. Periods 3 and 8 in primary treatment, and Period 4 in secondary treatment. Some reduced efficiency in the removals of biochemical oxygen demand, suspended solids, and iron during primary treatment occurred during Period 8 compared to Period 6. This is attributed to periodic bypassing of approximately 10 percent of the primary effluent into the final effluent and a high primary overflow rate. Final effluent concentrations of iron, therefore, were higher than optimum during Period 8.

The pH of the chemically treated wastewater (Table 9) did not change significantly upon the addition of the relatively small amounts of the acidic solution of ferric chloride. Very slight decreases (<.2 pH unit) were observed in laboratory studies and when ferric chloride was added before primary treatment (Periods 2 and 3). The natural alkalinity of the Grand Rapids wastewater (225 mg $CaCO_3$/l, Table 12) is sufficient to buffer at least 20 mg ferric iron/l (58.1 mg $FeCl_3$/l).

Chemical Additions and Overflow Rates

The concentrations of both ferric iron and the polyelectrolyte flocculant are two important parameters of the chemical removal process. The equal importance of designing and maintaining low hydraulic overflow rates during both primary and secondary clarification is emphasized. The hydraulic overflow rates existing during primary and secondary clarification have significant effects upon the removals of suspended solids and total phosphorus. The effects of excessively high overflow rates in hydraulically overloaded plants can be compensated in part by the addition of more ferric chloride and/or flocculant.

The increased removal of suspended solids in the Grand Rapids plant upon addition of another anionic polyelectrolyte (PURIFLOC A21 flocculant) has been reported previously[11]. Removals of suspended solids decreased with increased concentrations of suspended solids in the raw influent and with increased overflow rates as shown in Figure 10. The two families of curves were obtained with and without the addition of flocculant. An inorganic coagulant such as ferric chloride was not added in either case. For any selected combination of raw influent suspended solids concentration and primary overflow rate, the primary removal of suspended solids is increased by the addition of a flocculant. At an overflow rate of 385 cu m/day-sq m (1000 gpd/sq ft) and a raw influent suspended solids concentration of 128 mg/l, for example, the primary removal of suspended solids is increased from 47 to 70 percent upon the addition of the flocculant.

Decreased removals of total phosphorus can be expected when overflow rates are increased even though flocculation is acceptable. This influence also is illustrated for the various overflow rates shown in Figure 11. The individual curves are based on computer-generated contours (not shown) fitted through several hundred data (also not shown) collected during Period 2. The curves were essentially identical for both primary and secondary clarification. These curves are for illustrative purposes only and should not be construed for design purposes to represent conditions existing in all plants.

The removal of phosphorus from solution by ferric iron is not stoichiometric and increasing amounts of iron are required per unit of phosphorus removed as the phosphorus concentration decreases[3,16]. This effect is illustrated for any selected overflow rate in Figure 11. The decrease in removal of total phosphorus as overflow rate is increased

Figure 10 – **SUSPENDED SOLIDS REMOVAL AS A FUNCTION OF INFLUENT SUSPENDED SOLIDS CONCENTRATION AND OVERFLOW RATE WITH AND WITHOUT FLOCCULANT ADDITION**

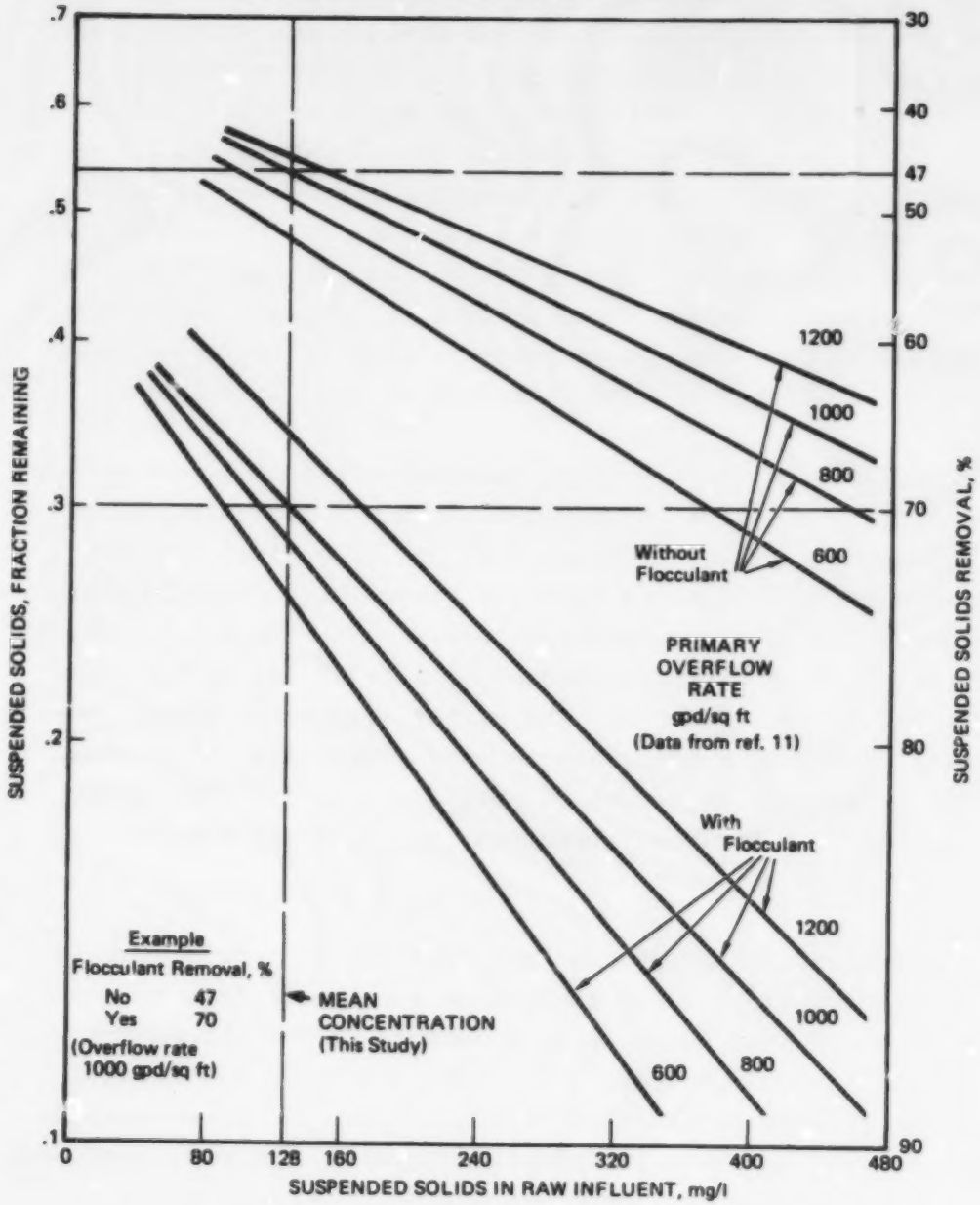
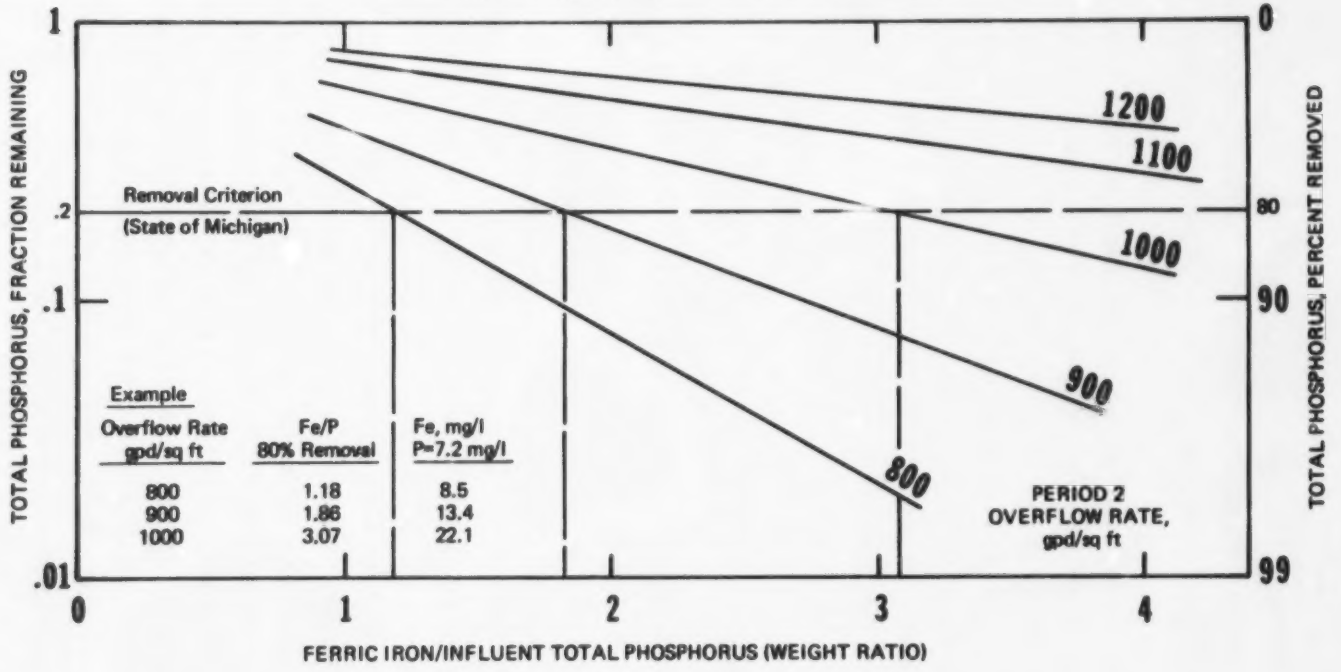


Figure 11 – TOTAL PHOSPHORUS REMOVAL AS A FUNCTION OF FERRIC IRON CONCENTRATION AND OVERFLOW RATE



can be compensated in part by the addition of more iron. Removal of 80% of the total phosphorus can be achieved, for example, at overflow rates of 30.8, 34.6 and 38.5 cu m/day-sq m (800, 900 and 1,000 gpd/sq ft), upon addition of 8.5, 13.4 and 22.1 mg Fe/l, respectively. These estimates assume a constant concentration of total phosphorus in the raw influent and the use of a constant amount of flocculant.

The comparative costs of chemical treatment are dependent upon the degree of phosphorus removal desired (Table 8). Total chemical costs for the Grand Rapids plant ranged from $.18-.61/kg ($.39-1.34/lb) total phosphorus removed. This corresponded to about $2.91-6.60/1000 cu m ($11-25/MG). About 90% of the total chemical cost was for ferric chloride and the remainder for the anionic flocculant.

Recycle Streams

There are three recycle streams entering the raw influent as shown in the detailed portion of Figure 5. The digester supernatant, the waste activated sludge, and the filtrate from vacuum filtration all contribute to the primary loadings of suspended solids, biochemical oxygen demand, the various phosphorus species, and heavy metals.

The effects of those recycle streams upon the overall chemical precipitation process should not be overlooked. Contributions of both soluble and total phosphorus, and suspended solids not receiving adequate chemical treatment can be significant. This is particularly true when the recycle stream addition points follow chemical addition points in the treatment flow sequence. It is reasonable to expect that any soluble phosphorus entering the wastestream after coagulant addition will not be insolubilized

with additional biological treatment. The sources of recycle include vacuum filtrate, waste activated sludge returned to primary, and digester supernate. An example of the contribution of one of these waste streams occurred in January, 1971. Average soluble phosphorus in the supernatant based on 9 samples was 439 mg/l. The total volume of supernatant returned to the raw sewage following coagulant addition was 2,289,000 gallons. This loading distributed equally for the average daily flow for the month is 0.80 mg/l or 12.8% of raw influent phosphorus.

Solids Handling

The relative distribution of solids in the various main and recycle process streams is altered by chemical treatment. The average values reported in Table 17 were taken directly from the monthly summary sheets of plant operation or subsequently calculated. Greater quantities of primary sludge solids generally were produced when phosphorus removal by chemical means was practiced. This usually was due to increased capture during primary treatment of solids normally present in the raw influent and to precipitated and flocculated iron-phosphate compounds. This increase is noted during periods of chemical treatment by the greater differences occurring between the dry weights of primary sludge weight actually measured and those calculated as the quantity: raw influent + waste activated + digester supernatant - primary effluent. The net increases in primary sludge production, particularly during Period 2 of about 30 percent, caused an overloading of the existing sludge handling facilities. Overloading also occurred after Period 8. The sludge produced during chemical treatment was generally easier to handle but additional capacity currently under construction is needed to handle the larger quantities.

TABLE 17

SOLIDS DISTRIBUTION IN VARIOUS PROCESS STREAMS

	Suspended Solids, 10^6 lb/mo												
Date	Raw Influent	Waste Activated Sludge	Digester Supernate	Primary Loading	Primary Effluent	Calculated Primary Sludge	Actual Primary Sludge	Difference (Actual-Calculated)	Final Effluent	Ferric Phosphate*	Chemically Precipitated Sludge**	FeCl$_3$ Added 10^6 lb/mo	Period***
	1	2	3	4=1+2+3	5	6=4-5	7	8=7-6	9	10	11	12	
1969-70	1.387	1.002	0.603	3.001	1.119	1.962	1.797	-0.165	0.426	0.110	0.110	-	1
7-70	1.576	1.030	.973	4.387	1.252	3.136	2.135	-1.001	.464	.085	.085	-	
8	2.266	1.441	.540	3.245	1.159	2.086	2.229	.143	.242	.112	.112	-	
9	1.480	1.097	.705	3.282	1.492	1.790	2.370	.579	.432	.126	.126	-	
10	1.696	1.292	.798	3.786	1.535	2.251	1.998	-.253	.371	.171	.171	-	
11	1.230	.229	.346	1.805	.362	1.443	2.179	.736	.220	.282	.276	0.182	2A
12	1.640	.682	.642	2.684	.502	2.183	3.459	1.276	.245	.261	.472	.495	2A
1-71	1.367	.760	.712	2.847	.613	2.234	2.439	.205	.248	.251	.489	.526	2A
2	1.220	.818	.045	2.083	.984	1.099	2.051	.952	.323	.192	.467	.530	2A
3	1.026	.352	.435	1.813	.858	.955	1.158	.160	.172	-	-	-	
4	1.386	1.142	.489	2.937	1.205	1.732	1.640	-.092	.382	.130	.130	-	
5	1.256	.802	.299	2.357	.890	1.467	2.472	1.005	.334	.204	.348	.378	2B
6	1.319	.452	.532	2.303	.640	2.110***	2.497	.387	.266	.254	.447	.468	2C
7	1.830	.332	1.149	2.511	.436	2.075	3.873	1.798	.263	.248	.566	.562	2C
8	1.345	.433	1.042	2.820	.504	2.316	3.481	1.165	.187	.267	.502	.581	2C
9	1.282	.256	.860	2.498	.387	2.099	2.785	.686	.323	.231	.481	.535	2C 0.7
10	1.352	.373	1.156	2.881	.610	2.271	3.456	1.185	.338	.201	.486	.550	2C, 3
11	-	.882	.100	-	.895	-	1.788	-	.294	-	-	.471	3
12	1.172	.427	.274	1.769	.488	1.981	1.612	.531	.619	.183	.403	.444	3, 4, 2D
1-72	1.210	.379	.867	1.655	.922	.733	1.406	.673	.564	.075	.075	-	
2	1.254	.700	.075	2.030	.955	1.074	1.637	.563	.389	.115	.115	-	
3	1.366	.463	.112	1.941	.976	.965	1.508	.542	.413	.061	.153	.122	3
4	1.633	.863	.182	2.588	.982	1.616	1.999	.383	.423	.250	.396	.469	3, 4
5	1.738	1.491	.552	3.691	1.214	2.477	2.659	.182	.229	.228	.228	-	
6	1.549	1.522	2.207	5.278	1.435	3.843	4.204	.362	.320	.156	.156	-	
7	1.448	.725	1.960	4.133	1.081	3.052	3.651	.599	.449	.075	.075	-	
8	1.851	.775	1.282	3.907	1.020	2.888	3.048	.160	.365	.149	.149	-	
9	1.377	1.020	1.161	3.559	.939	2.620	2.630	.010	.470	.066	.066	-	
10	1.686	1.041	1.311	4.038	1.050	3.008	2.639	-.369	.469	.035	.035	-	
11	1.381	1.221	1.775	4.286	.822	3.465	3.476	.012	.416	.057	.057	-	
12	1.410	.962	1.164	3.536	1.019	2.537	2.686	.149	.522	.098	.098	-	
1-73	1.768	1.411	.283	3.562	1.183	2.379	1.766	-.613	.520	.177	.172	.166	3
2	1.245	.894	.439	2.488	.914	1.574	1.656	.082	.582	.147	.190	.226	3
3	1.424	1.038	.683	2.943	1.222	1.721	1.624	-.097	1.046	.143	.265	.262	
4	1.486	1.414	1.060	3.960	.962	3.006	3.081	.075	.646	.113	.154	.174	
5	1.433	1.133	.460	3.025	.778	2.247	2.391	.143	.259	.057	.071	.031	
6	1.291	.841	.269	2.401	.634	1.767	2.210	.444	.304	.043	.043	-	

*Calculated from total phosphorus analyses only, not corrected for baseline.

**FePO$_4$ and Fe(OH)$_3$ calculated from total phosphorus and added iron concentration, not corrected for baseline.

***Includes .447 x 10^6 lb/mo lime sludge from water plant.

****For detailed chronology of operation see Table 5.

There were lesser quantities of waste activated sludge produced when chemicals were added to the raw influent. The quantities of chemically precipitated sludge can be estimated by assuming that all of the total phosphorus removed is precipitated as ferric phosphate [$FePO_4$] and that the added iron in excess of stoichiometric quantities for phosphorus precipitation is precipitated as ferric hydroxide [$Fe(OH)_3$]. The chemically precipitated sludge accounts for about half of the total primary sludge increase.

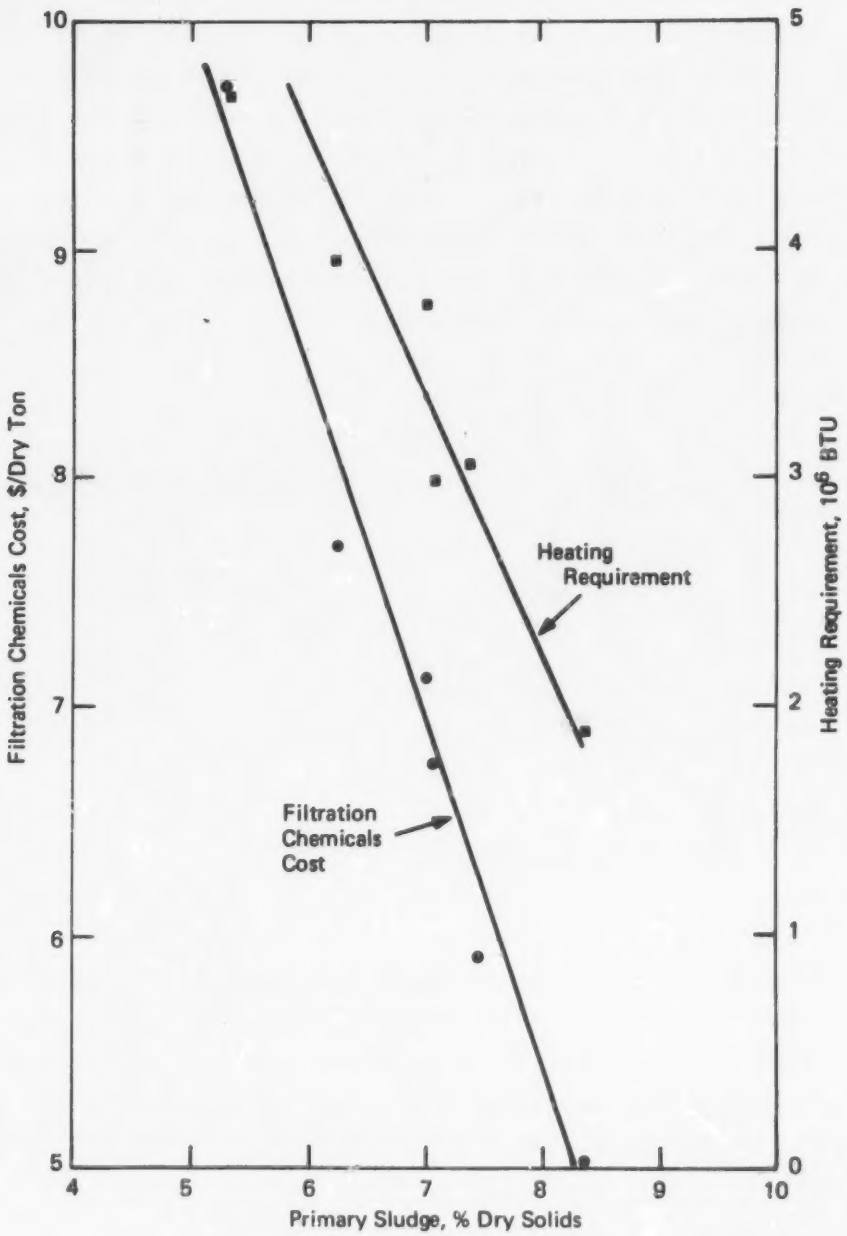
The iron and phosphorus contents of both sludges increase as a result of chemical treatment. Comparisons of phosphorus and iron concentrations in both primary and secondary (activated) sludges for selected periods are shown in Table 18. When chemical additions were made prior to primary clarification during Period 2, the phosphorus content of both sludges increased about one-third and the iron content increased about three-fold. When chemical additions were made just prior to secondary clarification during Period 6, the phosphorus content and the iron content of the secondary sludge increased about three-fold. The primary sludge solids were increased from an average of about 5-7 percent dry weight without chemical addition to 8 percent dry weight with chemical addition during primary treatment. This increase resulted in decreased chemical requirements for vacuum filtration and decreased heat requirements for incineration with attendant savings. Chemical costs for filtration and heat requirements for incineration as functions of solids content at the Grand Rapids plant are shown in Figure 12.

TABLE 18

COMPARISON OF SLUDGE COMPOSITIONS

Chemicals	Location	Period 1	Period 4	Period 6
		Concentrations, mg/l		
Ferric Iron	Primary	0	18.3	0
	Secondary	0	0	15.0
PURIFLOC A23 Flocculant	Primary	0	0.32	0
	Secondary	0	0	0.20
Component		Composition, mg/g		
Phosphorus	Primary	33.	43.	33. (est)
Iron	Primary	22.	86.	22. (est)
Phosphorus	Secondary	50.	65.	144.
Iron	Secondary	28.	76.	87.

Figure 12 – **FILTRATION CHEMICALS COSTS AND HEAT REQUIREMENTS AS FUNCTIONS OF SLUDGE SOLIDS CONTENT**



Sludge Filtration

One index for sludge dewatering improvement is the specific resistance to filtration. The specific resistance test is an extension of the Buchner funnel test[17]. It is a method of quantitatively comparing the filterability of sewage sludges. The calculated specific resistance to filtration is independent of most variables. Various sludges can be compared in an unbiased manner. A low specific resistance indicates a sludge with rapid filtration characteristics; a high specific resistance indicates poor filtration characteristics. A limited number of comparative data for two sludges and three different operating conditions at Grand Rapids are provided in Table 19.

TABLE 19
FILTRATION CHARACTERISTICS OF VARIOUS SLUDGES

Sludge	Chemical	Specific Resistance (m/kg x 10^{13})
Primary	None	7.9
	Flocculant only	4.95[11]
	Ferric chloride + flocculant	2.43 (this study)
Digested	None	13.6
	Flocculant only	6.66[11]

Filtration of mixed primary and secondary sludge collected using an anionic flocculant during primary treatment was conducted as part of a previous study[11]. Filtration of sludge collected using both ferric chloride and flocculant for phosphorus removal was conducted as part of the current grant.

SECTION X

ABBREVIATIONS

BOD = biochemical oxygen demand (five-day unless otherwise denoted)
Btu = British thermal unit
cm = centimeter
COD = chemical oxygen demand
cu = cubic
DO = dissolved oxygen
F.E. = final effluent
FRP = fiberglass-reinforced-plastic
ft = ft
gal = gallon
gpd = gallons/day
gpm = gallons/min
hp = horsepower
JTU = Jackson Turbidity Unit
kg = kilogram
km = kilometer
lb = pound
m = meter
MG = million gallons
mgd = million gallons/day
mg/g = milligrams/gram
mg/l = milligrams/liter
min = minute
ml = milliliter
N = nitrogen (atomic weight 14.01)
nm = nanometer
P = phosphorus (atomic weight 30.97)
P.E. = primary effluent
rem. = removal
rps = revolutions/second
s = second
sq = square
WRC = Water Resources Commission (State of Michigan)
cwt = hundred (pound) weight

SECTION XI

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SECTION XII

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SECTION XIII

APPENDICES

APPENDIX A
DETAILS OF ANALYTICAL TESTS

1. Ortho Phosphorus[18]*

Samples were initially filtered through 0.45 micron membrane filters. Ortho phosphorus was determined for each filtrate using the colorimetric method based on ortho phosphorus complexation with vanado-molybdophosphoric acid. A similar colorimetric method was used in the automatic ortho phosphorus analyzer described previously.

The filtrate was mixed with 10 ml of vanadate molybdate reagent in a volumetric flask until a final volume of 50 ml was reached. The absorbance was measured after 10 minutes of color development at a wavelength of 420 nm against a reagent blank. Ortho phosphorus concentration (mg P/l, P = elemental phosphorus, atomic weight 30.97) was calculated from a calibration curve previously prepared from standards and multiplied by the dilution factor of 1.25 (40 ml of sample brought to 50 ml).

2. Poly Phosphorus

The concentration of poly phosphorus (non-ortho soluble phosphorus)(mg P/l) was the calculated difference between soluble and ortho phosphorus analyses.

3. Soluble Phosphorus[19]

Soluble phosphorus (total filterable phosphorus)(mg P/l) consists of ortho phosphorus and various forms of poly phosphorus. Samples were filtered through a 0.45 micron membrane filter, and then acid digested according to the procedure for total phosphorus. The soluble phosphorus thus hydrolyzed to the ortho form was then determined colorimetrically as described above.

*See References

4. Suspended Phosphorus

The concentration of suspended phosphorus (particulate acid-hydrolyzable phosphorus)(mg P/l) was the calculated difference between total and soluble phosphorus analyses.

5. Total Phosphorus[20]

The stannous chloride method was used until January 1972. Thereafter the vanadate method with preliminary digestion was used. Equivalent results were obtained using each method on common samples. One ml of strong acid and 0.8 g potassium persulfate were added to 100 ml of sample in an Erlenmeyer flask. The sample was boiled to less than 75 ml (30 minutes or more), cooled, and brought back to a 100 ml volume with distilled water.

Acid-digested sewage was mixed with 10 ml of vanadate reagent in a volumetric flask to a final volume of 50 ml. After 10 minutes the absorbance was measured against a reagent blank at a wavelength of 420 nm. Total phosphorus (mg P/l) calculated from a calibration curve previously prepared from standards was multiplied by the dilution factor of 1.25 (40 ml of sewage diluted with reagent to 50 ml). For sludge samples, one ml volumes were diluted to 100 ml and then analyzed according to the above procedure. The result obtained was multiplied by a dilution factor of 125.

6. Total Biochemical Oxygen Demand (BOD_5)[21]

One BOD test was run on each sample using the following dilutions:

Raw sewage	4%
Primary effluent	4%
Final effluent	10%
Filtered raw influent	10%
Filtered primary effluent	10%
Filtered final effluent	20%

A portion of sample was pipetted into a 300 ml BOD bottle and diluted with dilution water of known dissolved oxygen (DO) concentration. The dilution water was prepared by adding sodium bicarbonate to distilled water and then aerating the solution. The BOD bottles and a blank were incubated for 4, 5, or 6 days at 20°C. After incubation, the samples and blank were removed and the DO concentrations determined with an oxygen meter (Yellow Springs Instrument Company Model 54 fitted with a No. 5420 oxygen probe and agitator). The DO meter was calibrated using water of known DO concentration determined by the azide modification of the iodometric method[22].

The following formula was used to determine the BOD of samples of 4 percent dilution.

$$\text{BOD (mg/l)} = \frac{a - b}{c}$$

On BOD dilutions greater than 4 percent, the initial DO was calculated. The following formula was used to determine the BOD.

$$\text{BOD (mg/l)} = \frac{(a \times e) - (c \times s) - b}{c}$$

For BOD dilutions greater than 4 percent which required seeding (with 1 percent primary effluent), the following formula was used to determine the BOD.

$$\text{BOD (mg/l)} = \frac{(a \times e) + (c \times s) - (g + B)}{c}$$

where a = DO of dilution water blank after incubator
b = sample DO after incubation
c = decimal fraction of sample
e = decimal fraction of dilution water
s = DO of original undiluted sample
g = 1 percent of the BOD of the primary effluent used for seed

Friday, Saturday, and Sunday samples were stored under refrigeration until Monday when they were set up for a 4-day BOD. Monday samples were set up for a 6-day BOD.

All 4-day BOD results were multiplied by 1.16 and all 6-day BOD results were multiplied by 0.91 to correct them to 5-day BOD values.

7. Soluble Biochemical Oxygen Demand

Each sample was homogenized in a high-speed blender and filtered through a 0.45 micron membrane filter prior to dilution, reseeding, and incubation. All other procedures were identical to those followed in determining the total biochemical oxygen demand.

8. Total Chemical Oxygen Demand (COD)

Values of COD were determined instrumentally (Precision AquaRator®). This involved injection of the samples into a combustion chamber, oxidation in a stream of carbon dioxide, and detection of the amount of carbon monoxide produced. Samples were homogenized in a high-speed blender. A 20 ml sample was then injected into the instrument. The maximum meter reading was recorded and the COD (mg/l) was then calculated from a standard curve.

9. Soluble Chemical Oxygen Demand

Each sample was homogenized in a high-speed blender and filtered through a 0.45 micron membrane filter prior to analysis which was then identical to that performed for total chemical oxygen demand.

10. Total Suspended Solids (Non-Filterable Residue)[23]

Suspended solids were determined by vacuum filtration of the sample through a Buchner funnel containing a glass fiber filter (9 cm, Reeve Angel No. 934 AH). The filters were

stored in a desiccator until used at which time they were weighed, placed in Buchner funnels and seated with distilled water. Samples were added and vacuum applied until all the liquid had passed through the filter. Sample volumes were 200 ml for influent and primary effluent, and 250 ml for final effluent. The filters were then placed in a 103°C drying oven for 45 minutes, cooled and weighed.

$$\text{Suspended solids (ml/l)} = \frac{A \times 1000}{B}$$

where A = mg suspended solids
B = ml sample

11. Volatile Suspended Solids[24]

The filter disc used for suspended solids was ignited in a muffle furnace at 550°C for 15 minutes, cooled, and weighed. Weight loss upon ignition, divided by the liters of sample, was reported as volatile suspended solids (mg/l).

12. Total Solids[25]

An evaporating dish was dried in an oven, stored in a desiccator and weighed. One hundred ml of sewage was added to the dish. The moisture was driven off on a steam bath. The dish was then cooled, placed in a desiccator and weighed. The weight of dry solids in milligrams multiplied by 10 equaled total solids (mg/l).

13. Heavy Metals

Chromium, copper, iron, nickel, and zinc (mg/l) were determined by atomic absorption spectroscopy (Model 290B Perkin-Elmer atomic absorption spectrophotometer). Samples were usually run on daily composited sewage. Occasionally, a composite sample (proportional to flow) was made of Monday through Friday samples and another composite was made of Saturday and Sunday samples. These composites were made

from the daily 24-hour composite samples which were homogenized in a high speed blender. Samples were added to a volume of 70 percent nitric acid calculated to be approximately 2.5 percent of the final volume. These samples were then analyzed using the atomic absorption spectrometer for concentrations from 0 to 10 mg/l of each metal. More concentrated samples were diluted 1:10 prior to analysis and the meter reading multiplied by a factor of 10.

14. Metals in Sludge

One ml samples of raw sludge, digested sludge, or mixed liquor were combined with 0.5 ml of concentrated HNO_3 and 5 ml of HCl in an Erlenmeyer flask. The samples were heated for 5 minutes on a hot plate. Samples were then diluted (to 200 ml for raw and digested sludge or to 25 ml for mixed liquor) and run on the atomic adsorption spectrophotometer described above using 2 mg/l standards. The meter reading (mg/l) was multiplied by the proper dilution factor (200 or 25).

15. Total Cyanide[26]

A sample volume of 250 ml was added to a modified Claisson flask. Then 20 ml of mercuric chloride reagent, 10 ml magnesium chloride reagent, and 12.5 ml of concentrated sulfuric acid were added to the flask. Hydrogen cyanide was distilled for 40 minutes into an evacuated gas washer containing 50 ml of 1 N sodium hydroxide. The contents of the gas washer were emptied into a 300 ml flask along with two water rinses of the gas washer. One-half ml of indicator solution was added to the sample which was then titrated with 0.0048 N silver nitrate. The milliliters of silver nitrate used then equalled cyanide (mg/l).

16. Ammonia Nitrogen[27]

One ml of zinc sulfate solution was added to 100 ml sample and mixed; 0.5 ml of NaOH solution was added and mixed. The sample was then filtered. Five ml of the treated sample were placed in a Nessler tube and the volume increased to 50 ml with distilled water. One ml of Nessler reagent was added. After 10 minutes of color development, the absorbance was measured at a wavelength of 425 nm using a spectrophotometer (Bausch and Lomb Spectronic 20). The ammonia nitrogen concentration (mg N/l) was calculated from a calibration curve previously prepared from standards and multiplied by a dilution factor of 10.

17. Total Nitrogen

A 20 ml sample was added to a micro Kjeldahl flask along with 30 ml of acid sulfate reagent and boiled slowly for 2 hours. The sample was transferred to an 800 ml Kjeldahl flask. Three hundred ml of ammonia-free water and 50 ml of sodium hydroxide-thiosulfate reagent were added. The sample was distilled into a 300 ml Erlenmeyer flask. The distillate was collected below the surface of a 50 ml boric acid indicating solution. Distillation continued until the 250 ml mark was reached. The distillate was collected below the surface of a 50 ml boric acid indicating solution. Distillation continued until the 250 ml mark was reached. The distillate was titrated with 0.02 N sulfuric acid. A blank was carried through all the steps and a correction applied to the results. The results were added to the ammonia concentration (mg/l) and the sum was recorded as total nitrogen.

$$\text{Kjeldahl nitrogen (mg/l)} = \frac{(D - E) \times 280}{\text{ml sample}}$$

$$\text{Total nitrogen (mg/l)} = \text{Kjeldahl} + \text{Ammonia nitrogen}$$

where D = titrant used on sample (ml)
E = titrant used on blank (ml)

18. Nitrate Nitrogen[28]

To each of two 50 ml beakers a 2 ml sample was added. Ten ml of sulfuric acid was added to two additional 50 ml beakers. One ml of distilled water was added to one sample for a blank. One ml of brucine sulfanilic acid reagent was added to the other sample. The blank was poured into one of the acid beakers and poured back and forth five or six times. The same procedure was followed with the remaining sample and acid beakers. After 3, but less than 10 minutes of color development, the absorbance was read at a wavelength of 410 nm using a spectrophotometer (Bausch and Lomb Spectronic 20). The nitrate nitrogen concentration (mg N/l) was calculated from a calibration curve previously prepared from standards. Chlorinated samples required one drop of sodium arsenite in 50 ml for every 0.1 mg/l of chlorine residual plus one drop in excess.

19. Nitrite Nitrogen[29]

Five ml of sewage (coagulated and filtered from the ammonia test) was added to a 50 ml volumetric flask containing 20 ml of nitrite-free distilled water. One ml of sulfanilic acid was added. After 3, but less than 10 minutes, 1 ml of sodium acetate and 1 ml of naphthylamine hydrochloride reagent was added. The sample was brought to 50 ml with nitrite-free distilled water. After 10 to 30 minutes the absorbance was measured at a wavelength of 520 nm against a reagent blank. The nitrite nitrogen concentration (mg N/l) was calculated from a calibration curve previously prepared from standards.

$$\text{Nitrite (mg N/l)} = \frac{\mu\text{g nitrite N}}{\text{ml sample}}$$

20. Alkalinity[30]

Bromcresol green-methyl red indicator was added to a 100 ml sample in a 250 ml Erlenmeyer flask. The sample was titrated with 0.02 N sulfuric acid until all blue color had disappeared.

$$\text{Total alkalinity (mg } CaCO_3/l) = \frac{B \times N \times 50{,}000}{\text{Sample (ml)}}$$

where B = titrant to endpoint (ml)
N = normality of acid

21. Chloride[31]

To a 50 ml sample in an Erlenmeyer flask 1 ml of potassium chromate indicator was added. The sample was titrated with 0.0282 N silver nitrate to the red endpoint.

$$Cl \text{ (mg/l)} = \frac{A \times N \times 35{,}450}{\text{ml sample}}$$

where A = titration for sample (ml)
N = normality of silver nitrate

22. Chlorine Residual[32]

A 200 ml sample was added to a sample jar and placed on the titrator. The agitator was started and 5 ml of phenylarsene oxide solution was added to the sample and mixed. Then 4 ml of buffer solution (pH 4) was added and mixed, followed by the addition of 1 ml of potassium iodide solution and again mixed. The adjusting knob on the amperometric titrator (Wallace and Tiernan) was rotated so that the pointer read approximately 20 on scale. Iodine solution (0.0282 N) was added in small increments from a 1 ml pipette until the endpoint was reached (when a small addition of iodine gave a permanent pointer deflection to the right).

Chlorine (mg/l) = phenylarsene oxide (ml) - 5 X iodine (ml)

23. Methylene Blue Active Substances in Sewage (MBAS)[33]

A 20 ml sample was added to a separatory funnel. The sample was made alkaline with 1 N NaOH using phenolphthalein as the indicator. The pink color was then discharged with 1 N sulfuric acid. Then 10 ml of chloroform and 25 ml of methylene blue reagent were added. The separatory funnel was rocked for 30 seconds and the bcttom chloroform layer was drawn off into a second separatory funnel. This procedure was repeated three times adding 10 ml of chloroform each time, rocking and drawing off the chloroform layer each time.

Fifty ml of wash solution were added to the second separatory funnel and shaken vigorously for 30 seconds. The chloroform layer was drawn off through glass wool into a 100 ml volumetric flask. The washing was repeated two more times each with 10 ml of chloroform, drawing off the chloroform into the volumetric flask each time. The sample was diluted to the mark with chloroform and the absorbance of the extracted sample solution was measured spectrophotometrically at a wavelength of 652 nm (Bausch and Lomb Spectronic 20). The MBAS, expressed as total apparent LAS (linear alkylsulfonate), were calculated from a calibration curve previously prepared from standards.

$$\text{Total apparent LAS (mg/l)} = \frac{\text{LAS (mg)}}{\text{sample (l)}}$$

24. Grease and Oil in Sewage[34]

To 500 ml of sewage in a 1000 ml beaker, 125 g of sodium chloride and 5 ml of concentrated HCl were added. The solution was allowed to stand for 24 hours. To the sample, 10 g of asbestos were added and stirred. The sample was then poured through an ashless filter paper (11 cm, Whatman No. 40) in a Buchner funnel. The filter and sample was placed in a Soxhlet extraction thimble. The Buchner funnel

and beaker were wiped out with a cotton ball soaked with hexane which was added to the thimble. The thimble was placed in a Soxhlet extraction tube and placed over a 300 ml flat bottomed flask (previously dried and weighed) containing 200 ml of hexane. The top of the extraction tube was connected to the bottom of a reflux condenser. The sample was refluxed for 4 hours. The tube was removed and hexane distilled off. The flask and remaining residue was again weighed. The second weighing was subtracted from the first.

$$\text{Grease and oil (mg/l)} = \frac{\text{mg increase in weight of flask X 1000}}{\text{ml sample used}}$$

25. Grease Content of Sludges[35]

A 20 g sample of sludge was weighed in a beaker and one ml of HCl was added. Previously dried magnesium sulfate monohydrate was added and mixed. The sample was transferred to a Soxhlet extraction thimble and extracted with hexane into a previously dried and weighed 300 ml flat-bottomed flask. After 4 hours of extraction the hexane was distilled from the flask which was dried in a desiccator and weighed.

$$\text{Grease (\% dry solids)} = \frac{\text{gain in weight of flask (g) x 100}}{\text{weight of wet solids (g) X dry solids (\%)}}$$

26. Hydrocarbon and Fatty Matter Content of Grease[36]

Into the flask used for the grease analysis 70 ml of hexane was poured, 10 ml at a time. Each 10 ml portion of hexane was passed through an adsorption column of activated alumina and collected in a tared flask. The hexane was distilled from the flask which was then cooled in a desiccator and weighed.

$$\text{Hydrocarbon (\%)} = \frac{A \text{ X } 100}{B}$$

where A = increase in weight of flask (mg)
B = total grease (mg)

27. Total Coliform Group[37]

One ml of final effluent was filtered through a sterile 47 mm diameter 0.45 micron filter. This filter was then plated on previously prepared M-Endo broth and incubated in air for 24 hours at 35.5°C. Round colonies with a green sheen were counted and reported as colonies per 100 ml of sample.

$$\text{Colonies (no./100 ml)} = \frac{\text{colonies counted X 100}}{\text{filtered sample (ml)}}$$

28. Fecal Coliform Group[38]

A ten ml sample was filtered through a sterile 47 mm diameter 0.45 micron filter. This filter was plated on previously prepared MFC broth and incubated at 44.5°C for 24 hours in a water bath. The blue colonies were counted and reported as colonies per 100 ml of sample.

$$\text{Colonies (no./100 ml)} = \frac{\text{colonies counted x 100}}{\text{filtered sample (ml)}}$$

29. Fecal Streptococcal Group[39]

A 20 ml sample was filtered through a sterile 47 mm 0.45 micron filter. The filter was plated on previously prepared KF Streptococcus agar and incubated for 48 hours at 35.5°C in air. The red colonies were counted and reported as colonies per 100 ml of sample.

$$\text{Colonies (no./100 ml)} = \frac{\text{colonies counted X 100}}{\text{filtered sample (ml)}}$$

APPENDIX B
PROBABILITY ANALYSIS

A series of observations collected for a given system under various conditions or at various times can be arranged in increasing order of magnitude to form an array of values that can be analyzed using conventional statistical methods. The cumulative occurrence of any one observation can be expressed as a percentage less than or equal to the numerical value of that observation. The cumulative frequency for a normal population of values then can be plotted as a symmetrical S-shaped curve. By the use of a special probability scale this curve can be transformed into a straight line. This linear form is particularly convenient for the determination of certain statistical parameters such as the mean and standard deviation.

The statistical mean of a given set of data is the intercept of the linearized cumulative probability plot at the 50 percent occurrence level. The statistical mean will approach the arithmetical mean as the data become more normal. The standard deviation of the data is the slope of this line. Departure from a straight line on the normal probability plot is a sign of skewness of another type of statistical distribution. It should be emphasized that the standard deviation of such data is usually meant as a deviation from the mean occurrence and not a deviation from a mean analysis. For example, total phosphorus might occur 5.6 ± 2.3 mg P/l within averaged analyses for a population of 30 samples but range 3.3 ± 0.2 mg P/l within a series of replicate analyses on a single sample of this population. The deviation of occurrence is usually much larger than the deviation of analysis. A population of a dozen or more values is usually required for the statistical analysis to be significant. For very large populations the data can be grouped within consecutive ranges of values.

The following procedure was followed in developing a statistical analysis of data assumed to follow a normal form.

1. Arrange the n-values of data (sample number = i = 1,2,.. ....,n) in a table by increasing numerical order.

2. Determine the cumulative percentages of occurrence as the quotient 100i/(n+1).

3. Plot the data at the appropriate cumulative percentages of occurrence on probability paper.

4. Establish the line of best fit using a least-squares procedure.

5. Determine the statistical mean as the intercept at the 50 percent occurrence level.

6. Determine the standard deviation as the difference between the mean (50 percent occurrence level) and either the 84.13 percent or the 15.87 percent occurrence level.

The mean and standard deviation of parameters such as suspended solids, biochemical oxygen demand, total phosphorus, etc., can be determined quite easily using graphical techniques. Differences between influent and effluent values of a given parameter for two distinct populations, such as two influents or two effluents, can be distinguished readily by overlaying the appropriate probability plots if consistent scales are used. Most populations of data of the various parameters of waste treatment expressed in absolute units are normally distributed and lead to well-behaved linear correlations.

Although corresponding separate populations of influent and effluent values may lead to linear plots, the difference between them, expressed as a dimensionless ratio or percent removal, may be skewed. This condition is most prevalent as the removals asymptotically approach 100 percent. Removals less than 0 percent or greater than 100 percent usually are indicative of analytical or sampling errors, or of unusual occurrences within the treatment plant such as operational upsets or intermittent internal flows. For certain parameters the data alternatively may be assumed to follow a logarithmic normal probability distribution or some other skewed distribution.

Probability plots of normal data were created by a customized computer program using the IBM 1130 Computing System and an IBM 1627 plotter. The means and standard deviations were determined by fitting the data using a least squares procedure. The program provided fast, accurate, and convenient statistical analyses and simultaneous graphical presentations.

The data for each period for each variable at each location were plotted using normal probability coordinates resulting in a maximum of 14 graphs for each period. Those days for which the concentrations of either treatment chemical, ferric iron or PURIFLOC A23 flocculant, were greater than one standard deviation from the fitted least squares line were discarded. Those days for which two or more combined analyses of biochemical oxygen demand, suspended solids, any of the five phosphorus species, or any five metals for a given day exceeded this deviation were also discarded. These deviant data usually occurred when chemical feed pumps were started up or shut down, or when severe disruptions in plant operation occurred. Chemical/physical equilibrium could not always be assured during the first and last days of a given period of study.

The total days listed in Table B-1, therefore, were reduced by this selection process. The number of good and bad days represent the maximum possible in each category. Occasional missing data reduce these numbers further for individual variables. Greater than 80 percent of the available data in almost all periods was considered to be statistically representative of those values expected during normal plant operation.

TABLE B-1
PERIODS OF STUDY

	PERIOD												
	1	2A	2B	2C	2D	2	3	4	5A	5B	6	7	8
Beginning	07-01-69	11-03-70	05-10-71	06-07-71	12-16-71	11-03-70	10-21-71	12-10-71	04-12-72	04-18-72	05-10-72	09-09-71	01-01-73
	182	672	860	888	1080	672	1024	1074	1198	1204	1226	982	1462
Ending	06-30-70	02-25-71	05-25-71	10-20-71	12-29-71	12-29-71	12-09-71	12-15-71	05-09-72	04-30-72	06-03-72	09-13-71	02-28-73
	546	786	874	1023	1093	1093	1073	1079	1225	1216	1250	986	1520
Total Days	365	115	15	136	14	280	50	6	15	13	25	5	59
Good Days	-	84	12	112	10	218	46	5	12	12	22	5	45
Bad Days	-	31	3	24	4	62	4	1	3	1	3	-	14
% Good	-	73	80	82	71	78	92	83	80	92	88	-	76

Period 1 No Chemical Treatment
Period 2 Metal + Flocculant Addition to Primary
Period 3 Metal Addition Only to Primary
Period 4 Split Addition of Metal to Both Primary and Secondary + Flocculant Only to Primary
Period 5 Metal Addition Only to Secondary
Period 6 Metal + Flocculant Addition to Secondary
Period 7 Metal + Anionic Flocculant Addition to Primary + Cationic Flocculant Addition to Secondary
Period 8 Split Addition of Metal to Both Primary and Secondary + Flocculant Addition Only to Secondary

APPENDIX C
LISTINGS OF TABULATED DATA

Listings of tabulated data are included in Table C-1. The complete tabulations of over 58,000 individual values are too detailed for this report.

Representative listings of all available forms for December 1970 are included for illustration. Missing or incalculable data are designated by asterisks (*).

TABLE C-1

LISTINGS OF TABULATED DATA

Definition	Months	Inclusive Days
Phosphorus Species, Raw Influent	38	182-1277, 1462-1520
Phosphorus Species, Primary Effluent	38	182-1277, 1462-1520
Phosphorus Species, Final Effluent	38	182-1277, 1462-1520
Iron, BOD, and Suspended Solids	38	182-1277, 1462-1520
Metal Removals	38	182-1277, 1462-1520
Weir Overflow Rates and Total Phosphorus Levels	20	672-1277

FERRIC CHLORIDE AND ORGANIC POLYELECTROLYTES FOR THE REMOVAL OF PHOSPHORUS

GRANT NO. 11010 ENK, GRAND RAPIDS, MICHIGAN.

PHOSPHORUS SPECIES FOR DECEMBER, 1970, PERIOD 2, RAW INFLUENT

DAYPMOY	FLOW	FE+3	FLOC	OP	PP	SP	XP	TP	OP/TP	PP/TP	SP/TP	XP/TP
7002120	50.2	17.19	0.18	1.00	3.00	4.00	0.80	4.80	0.208	0.625	0.833	0.167
7012120	43.9	17.19	0.33	1.80	1.60	3.40	4.00	7.40	0.243	0.216	0.459	0.541
7022120	42.9	17.19	0.42	1.90	1.30	3.20	3.40	6.60	0.288	0.197	0.485	0.515
7032120	47.0	17.19	0.31	1.60	2.60	4.20	1.10	5.30	0.302	0.491	0.792	0.208
7042120	40.7	17.19	0.25	2.00	4.60	6.60	2.60	9.20	0.217	0.500	0.717	0.283
7052120	39.1	17.19	0.15	1.65	3.35	5.00	2.80	7.80	0.212	0.429	0.641	0.359
7062120	45.2	17.19	0.40	1.30	2.90	4.20	3.00	7.20	0.181	0.403	0.583	0.417
7072120	45.0	17.19	0.32	1.90	2.10	4.00	1.60	5.60	0.339	0.375	0.714	0.286
7082120	45.9	17.19	0.32	1.60	0.0	1.60	5.60	7.20	0.222	0.0	0.222	0.778
7092120	45.2	17.19	0.32	1.30	2.30	3.60	3.30	6.90	0.188	0.333	0.522	0.478
7102120	44.6	17.19	0.30	1.50	4.60	6.10	0.0	6.10	0.246	0.754	1.000	0.0
7112120	46.8	17.19	0.38	2.40	3.20	5.60	1.30	6.90	0.348	0.464	0.812	0.188
7122120	41.0	17.19	0.31	2.30	4.10	6.40	1.60	8.00	0.288	0.512	0.800	0.200
7132120	47.0	17.19	0.43	1.80	2.20	4.00	2.40	6.40	0.281	0.344	0.625	0.375
7142120	46.7	17.19	0.20	1.50	1.90	3.40	2.40	5.80	0.259	0.328	0.586	0.414
7152120	46.1	17.19	0.31	1.40	1.50	2.90	2.90	5.80	0.241	0.259	0.500	0.500
7162120	49.1	17.19	0.31	1.40	1.80	3.20	2.90	6.10	0.230	0.295	0.525	0.475
7172120	49.2	17.19	0.33	1.20	4.00	5.20	0.40	5.60	0.214	0.714	0.929	0.071
7182120	53.2	17.19	0.33	1.50	2.50	4.00	2.10	6.10	0.246	0.410	0.656	0.344
7192120	44.9	17.19	0.33	1.75	2.25	4.00	7.20	11.20	0.156	0.201	0.357	0.643
7202120	48.2	17.19	0.32	1.45	3.35	4.80	0.0	4.80	0.302	0.698	1.000	0.0
7212120	50.8	17.19	0.33	1.30	2.10	3.40	3.00	6.40	0.203	0.328	0.531	0.469
7222120	49.2	17.19	0.31	1.30	2.10	3.40	3.00	6.40	0.203	0.328	0.531	0.469
7232120	43.4	17.19	0.33	1.20	4.10	5.30	1.60	6.90	0.174	0.594	0.768	0.232
7242120	38.0	17.19	0.33	1.30	2.10	3.40	1.10	4.50	0.289	0.467	0.756	0.244
7252120	38.7	17.19	0.33	0.95	3.55	4.50	2.10	6.60	0.144	0.538	0.682	0.318
7262120	38.2	17.19	0.33	1.45	2.75	4.20	1.60	5.80	0.250	0.474	0.724	0.276
7272120	44.7	17.19	0.33	0.20	0.80	1.00	7.00	8.00	0.025	0.100	0.125	0.875
7282120	46.0	17.19	0.33	1.40	2.60	4.00	2.40	6.40	0.219	0.406	0.625	0.375
7292120	44.8	17.19	0.33	0.70	1.70	2.40	4.60	7.00	0.100	0.243	0.343	0.657
7302120	41.3	17.19	0.31	1.45	3.85	5.30	0.80	6.10	0.238	0.631	0.869	0.131

END OF DECEMBER, 1970

FERRIC CHLORIDE AND ORGANIC POLYELECTROLYTES FOR THE REMOVAL OF PHOSPHORUS

GRANT NO. 11010 ENK, GRAND RAPIDS, MICHIGAN

PHOSPHORUS SPECIES FOR DECEMBER, 1970, PERIOD 2, PRI EFFLUENT

DAYPMOY	FLOW	FE+3	FLOC	OP	PP	SP	XP	TP	OP/TP	PP/TP	SP/TP	XP/TP
7002120	50.2	17.19	0.18	0.01	1.59	1.60	1.60	3.20	0.003	0.497	0.500	0.500
7012120	43.9	17.19	0.33	0.20	0.0	0.20	2.70	2.90	0.069	0.0	0.069	0.931
7022120	42.9	17.19	0.42	0.70	0.60	1.30	0.80	2.10	0.333	0.286	0.619	0.381
7032120	47.0	17.19	0.31	0.01	0.49	0.50	1.30	1.80	0.006	0.272	0.278	0.722
7042120	40.7	17.19	0.25	0.40	0.40	0.80	1.30	2.10	0.190	0.190	0.381	0.619
7052120	39.1	17.19	0.15	0.30	0.70	1.00	0.80	1.80	0.167	0.389	0.556	0.444
7062120	45.2	17.19	0.40	0.01	0.79	0.80	1.60	2.40	0.004	0.329	0.333	0.667
7072120	45.0	17.19	0.32	0.15	0.85	1.00	0.0	1.00	0.150	0.850	1.000	0.0
7082120	45.9	17.19	0.32	0.30	0.50	0.80	1.30	2.10	0.143	0.238	0.381	0.619
7092120	45.2	17.19	0.32	0.15	1.45	1.60	1.00	2.60	0.058	0.558	0.615	0.385
7102120	44.6	17.19	0.30	0.01	2.39	2.40	0.0	2.40	0.004	0.996	1.000	0.0
7112120	46.8	17.19	0.38	0.01	0.99	1.00	2.20	3.20	0.003	0.309	0.313	0.687
7122120	41.0	17.19	0.31	0.40	1.70	2.10	1.10	3.20	0.125	0.531	0.656	0.344
7132120	47.0	17.19	0.43	0.55	0.25	0.80	1.00	1.80	0.306	0.139	0.444	0.556
7142120	46.7	17.19	0.20	0.80	1.80	2.60	0.80	3.40	0.235	0.529	0.765	0.235
7152120	46.1	17.19	0.31	0.80	1.60	2.40	1.30	3.70	0.216	0.432	0.649	0.351
7162120	49.1	17.19	0.31	0.95	1.45	2.40	0.80	3.20	0.297	0.453	0.750	0.250
7172120	49.2	17.19	0.33	0.20	1.40	1.60	0.0	1.60	0.125	0.875	1.000	0.0
7182120	53.2	17.19	0.33	0.30	0.70	1.00	0.80	1.80	0.167	0.389	0.556	0.444
7192120	44.9	17.19	0.33	0.20	0.30	0.50	1.30	1.80	0.111	0.167	0.278	0.722
7202120	48.2	17.19	0.32	0.70	2.20	2.90	0.0	2.90	0.241	0.759	1.000	0.0
7212120	50.8	17.19	0.33	0.20	0.60	0.80	2.60	3.40	0.059	0.176	0.235	0.765
7222120	49.2	17.19	0.31	0.20	0.60	0.80	2.60	3.40	0.059	0.176	0.235	0.765
7232120	43.4	17.19	0.33	0.40	0.40	0.80	0.80	1.60	0.250	0.250	0.500	0.500
7242120	38.0	17.19	0.33	0.15	0.05	0.20	0.80	1.00	0.150	0.050	0.200	0.800
7252120	38.7	17.19	0.33	0.20	0.30	0.50	0.50	1.00	0.200	0.300	0.500	0.500
7262120	38.2	17.19	0.33	0.15	0.05	0.20	1.90	2.10	0.071	0.024	0.095	0.905
7272120	44.7	17.19	0.33	0.55	0.45	1.00	1.10	2.10	0.262	0.214	0.476	0.524
7282120	46.0	17.19	0.33	0.45	1.35	1.80	1.60	3.40	0.132	0.397	0.529	0.471
7292120	44.8	17.19	0.33	1.45	1.95	3.40	1.10	4.50	0.322	0.433	0.756	0.244
7302120	41.3	17.19	0.31	0.15	0.35	0.50	1.30	1.80	0.083	0.194	0.278	0.722

END OF DECEMBER, 1970

FERRIC CHLORIDE AND ORGANIC POLYELECTROLYTES FOR THE REMOVAL OF PHOSPHORUS

GRANT NO. 11010 ENK, GRAND RAPIDS, MICHIGAN

PHOSPHORUS SPECIES FOR DECEMBER, 1970, PERIOD 2, FIN EFFLUENT

DAYPMDY	FLOW	FE+3	FLOC	OP	PP	SP	XP	TP	OP/TP	PP/TP	SP/TP	XP/TP
7002120	50.2	17.19	0.18	0.30	2.30	2.60	0.30	2.90	0.103	0.793	0.897	0.103
7012120	43.9	17.19	0.33	0.70	0.10	0.80	2.60	3.40	0.206	0.029	0.235	0.765
7022120	42.9	17.19	0.42	0.45	0.85	1.30	0.50	1.80	0.250	0.472	0.722	0.278
7032120	47.0	17.19	0.31	0.15	0.65	0.80	1.30	2.10	0.071	0.310	0.381	0.619
7042120	40.7	17.19	0.25	0.15	0.65	0.80	2.10	2.90	0.052	0.224	0.276	0.724
7052120	39.1	17.19	0.15**********			0.20	3.00	3.20**********			0.063	0.937
7062120	45.2	17.19	0.40	0.45	2.75	3.20	1.30	4.50	0.100	0.611	0.711	0.289
7072120	45.0	17.19	0.32	0.70	0.10	0.80	0.0	0.80	0.875	0.125	1.000	0.0
7082120	45.9	17.19	0.32	0.15	2.25	2.40	0.20	2.60	0.058	0.865	0.923	0.077
7092120	45.2	17.19	0.32	0.15	1.45	1.60	0.20	1.80	0.083	0.806	0.889	0.111
7102120	44.6	17.19	0.30	0.01	0.79	0.80	0.80	1.60	0.006	0.494	0.500	0.500
7112120	46.8	17.19	0.38	0.01	0.19	0.20	0.30	0.50	0.020	0.380	0.400	0.600
7122120	41.0	17.19	0.31	0.45	0.35	0.80	0.80	1.60	0.281	0.219	0.500	0.500
7132120	47.0	17.19	0.43	1.00	1.10	2.10	0.50	2.60	0.385	0.423	0.808	0.192
7142120	46.7	17.19	0.20	0.70	0.60	1.30	0.80	2.10	0.333	0.286	0.619	0.381
7152120	46.1	17.19	0.31	1.40	1.00	2.40	0.50	2.90	0.483	0.345	0.828	0.172
7162120	49.1	17.19	0.31	1.20	1.20	2.40	0.20	2.60	0.462	0.462	0.923	0.077
7172120	49.2	17.19	0.33	0.30	0.70	1.00	0.0	1.00	0.300	0.700	1.000	0.0
7182120	53.2	17.19	0.33	0.40	0.90	1.30	0.30	1.60	0.250	0.563	0.812	0.188
7192120	44.9	17.19	0.33	0.15	0.35	0.50	0.80	1.30	0.115	0.269	0.385	0.615
7202120	48.2	17.19	0.32	0.30	1.00	1.30	0.70	2.00	0.150	0.500	0.650	0.350
7212120	50.8	17.19	0.33	0.45	0.75	1.20	0.40	1.60	0.281	0.469	0.750	0.250
7222120	49.2	17.19	0.31	0.45	0.75	1.20	0.40	1.60	0.281	0.469	0.750	0.250
7232120	43.4	17.19	0.33	0.45	0.35	0.80	0.20	1.00	0.450	0.350	0.800	0.200
7242120	38.0	17.19	0.33	0.15	0.05	0.20	0.60	0.80	0.187	0.063	0.250	0.750
7252120	38.7	17.19	0.33	0.20	0.0	0.20	0.60	0.80	0.250	0.0	0.250	0.750
7262120	38.2	17.19	0.33	0.30	0.20	0.50	0.0	0.50	0.600	0.400	1.000	0.0
7272120	44.7	17.19	0.33	0.40	0.40	0.80	0.50	1.30	0.308	0.308	0.615	0.385
7282120	46.0	17.19	0.33	1.10	1.00	2.10	0.50	2.60	0.423	0.385	0.808	0.192
7292120	44.8	17.19	0.33	0.70	1.10	1.80	0.80	2.60	0.269	0.423	0.692	0.308
7302120	41.3	17.19	0.31	0.30	0.50	0.80	0.50	1.30	0.231	0.385	0.615	0.385

END OF DECEMBER, 1970

DAY = DAY OF MONTH
P = PERIOD OF STUDY
1 = PERIOD OF NO CHEMICAL TREATMENT
2 = PERIOD OF METAL + FLOCCULANT ADDITION TO PRIMARY
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MO = MONTH
Y = YEAR
FLOW = DAILY AVERAGE FLOW, MGD
FE+3 = FERRIC IRON, MG/L
FLOC = PURIFLOC A23 FLOCCULANT, MG/L
OP = ORTHO PHOSPHORUS, MG/L
PP = POLY P, MG/L (PP = SP - OP)
SP = SOLUBLE P, MG/L
XP = SUSPENDED P, MG/L (XP = TP - SP)
TP = TOTAL P, MG/L

FERRIC CHLORIDE AND ORGANIC POLYELECTROLYTES FOR THE REMOVAL OF PHOSPHORUS

GRANT NO. 11010 ENK, GRAND RAPIDS, MICHIGAN

IRON, BOD, AND SUSPENDED SOLIDS FOR DECEMBER, 1970 , PERIOD 2

DAYPHOY	FLOW	FE+3	FLOC	FE0	FE1	FE2	PRFE	ORFE	BOD0	BOD1	BOD2	PRBD	ORBD	SUS0	SUS1	SUS2	PRSS	ORSS
7002120	50.2	17.19	0.18	0.08	1.10	0.70	*****	-775.	103.	43.	13.	58.	87.	136.	40.	44.	71.	68.
7012120	43.9	17.19	0.33	1.10	0.35	0.30	68.	73.	98.	35.	17.	64.	83.	116.	24.	37.	79.	68.
7022120	42.9	17.19	0.42	2.65	0.32	0.68	88.	74.	100.	35.	14.	65.	86.	221.	38.	37.	83.	83.
7032120	47.0	17.19	0.31	1.12	1.45	1.25	-29.	-12.	**********					102.	38.	31.	63.	70.
7042120	40.7	17.19	0.25	0.69	1.68	0.92	-143.	-33.	**********					92.	43.	19.	53.	79.
7052120	39.1	17.19	0.15	0.35	1.15	0.79	-229.	-126.	**********					72.	25.	17.	65.	76.
7062120	45.2	17.19	0.40	1.08	1.18	1.35	-9.	-25.	98.	39.	15.	60.	85.	116.	30.	45.	74.	61.
7072120	45.0	17.19	0.32	1.52	0.45	0.82	70.	46.	96.	35.	17.	64.	82.	111.	28.	33.	75.	70.
7082120	45.9	17.19	0.32	1.45	1.32	1.00	9.	31.	110.	45.	20.	59.	82.	116.	45.	20.	61.	83.
7092120	45.2	17.19	0.32	0.55	0.43	0.35	22.	36.	113.	58.	14.	49.	88.	113.	24.	15.	79.	87.
7102120	44.6	17.19	0.30	2.36	2.00	0.81	15.	66.	116.	34.	17.	71.	85.	119.	49.	14.	59.	88.
7112120	46.8	17.19	0.38	0.55	3.71	1.15	-575.	-109.	79.	20.	22.	75.	72.	131.	71.	20.	46.	85.
7122120	41.0	17.19	0.31	1.77	1.97	1.05	-11.	41.	76.	40.	14.	47.	82.	112.	61.	19.	46.	83.
7132120	47.0	17.19	0.43	1.05	1.45	1.08	-38.	-3.	91.	36.	21.	60.	77.	113.	40.	28.	65.	75.
7142120	46.7	17.19	0.20	1.78	0.31	0.35	83.	80.	105.	48.	20.	54.	81.	116.	48.	23.	59.	80.
7152120	46.1	17.19	0.31	3.33	1.92	0.75	42.	77.	93.	45.	27.	52.	71.	108.	58.	24.	46.	78.
7162120	49.1	17.19	0.31	3.32	2.11	0.70	36.	79.	85.	50.	17.	41.	80.	130.	52.	16.	60.	88.
7172120	49.2	17.19	0.33	0.85	0.64	0.22	25.	74.	94.	34.	21.	64.	78.	104.	32.	19.	69.	82.
7182120	53.2	17.19	0.33	0.35	0.40	0.32	-14.	9.	91.	40.	19.	56.	79.	94.	30.	12.	68.	87.
7192120	44.9	17.19	0.33	0.10	0.24	0.58	-140.	-480.	66.	33.	10.	50.	85.	64.	22.	11.	66.	83.
7202120	48.2	17.19	0.32	0.82	2.12	0.58	-159.	29.	82.	46.	12.	44.	85.	102.	55.	14.	46.	86.
7212120	50.8	17.19	0.33	1.38	1.95	0.57	-41.	59.	108.	70.	11.	35.	90.	121.	49.	15.	60.	88.
7222120	49.2	17.19	0.31	2.61	3.60	0.88	-38.	66.	105.	70.	14.	33.	87.	157.	67.	19.	57.	88.
7232120	43.4	17.19	0.33	0.88	2.02	1.15	-130.	-31.	82.	44.	20.	46.	76.	72.	56.	8.	22.	89.
7242120	38.0	17.19	0.33	0.25	1.15	0.60	-360.	-140.	62.	26.	23.	58.	83.	52.	31.	21.	40.	60.
7252120	38.7	17.19	0.33	0.34	1.40	0.70	-312.	-106.	60.	21.	12.	65.	80.	95.	52.	9.	45.	91.
7262120	38.2	17.19	0.33	0.35	1.91	0.78	-446.	-123.	68.	34.	10.	50.	85.	89.	52.	7.	42.	92.
7272120	44.7	17.19	0.33	1.20	1.25	0.90	-4.	25.	**********					129.	28.	27.	78.	79.
7282120	46.0	17.19	0.33	3.40	2.33	1.21	31.	64.	**********					114.	50.	19.	56.	83.
7292120	44.8	17.19	0.33	0.38	0.35	0.18	8.	53.	115.	58.	28.	50.	76.	112.	35.	19.	69.	83.
7302120	41.3	17.19	0.31	1.81	2.75	1.58	-52.	13.	95.	34.	13.	64.	86.	124.	55.	20.	56.	84.

END OF RECORD FOR DECEMBER, 1970

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FE = IRON, MG/L
BOD = BIOCHEMICAL OXYGEN DEMAND, MG/L
SUS = SUSPENDED SOLIDS, MG/L
0 = RAW INFLUENT
1 = PRIMARY EFFLUENT
2 = FINAL EFFLUENT
PR = PRIMARY REMOVAL, PER CENT
OR = OVERALL REMOVAL, PER CENT

FERRIC CHLORIDE AND ORGANIC POLYELECTROLYTES FOR THE REMOVAL OF PHOSPHORUS

GRANT NO. 11010 ENK, GRAND RAPIDS, MICHIGAN

METAL REMOVALS FOR DECEMBER, 1970, PERIOD 2

DAYPMOY	CRO	CR1	CR2	PRCR	ORCR	NIO	NI1	NI2	PRNI	ORNI	CUO	CU1	CU2	PRCU	ORCU	ZNO	ZN1	ZN2	PRZN	ORZN
7002120	0.70	0.60	0.25	14.	64.	0.90	0.92	0.92	-2.	-2.	0.25	0.25	0.17	0.	32.	1.20	0.69	0.45	42.	62.
7012120	1.82	0.80	0.10	56.	95.	1.42	0.98	0.93	31.	35.	0.31	0.14	0.24	55.	23.	1.20	0.50	0.39	58.	67.
7022120	0.45	0.35	0.15	22.	67.	0.98	0.74	1.04	24.	-6.	0.38	0.18	0.26	53.	32.	1.30	0.52	0.65	60.	50.
7032120	1.45	0.92	0.30	37.	79.	1.25	1.05	1.00	16.	20.	1.45	0.80	0.95	45.	34.	1.51	0.86	0.86	43.	43.
7042120	1.70	1.55	0.62	9.	64.	0.97	0.85	0.91	12.	6.	0.50	0.40	0.57	20.	-14.	0.90	0.75	0.71	17.	21.
7052120	0.11	0.10	0.19	9.	-73.	0.59	0.56	0.65	5.	-10.	0.10	0.22	0.17	-120.	-70.	0.45	0.55	0.51	-22.	-13.
7062120	1.12	0.56	0.20	50.	82.	1.40	1.20	1.05	14.	25.	0.90	0.50	0.50	44.	44.	0.85	0.50	0.50	41.	41.
7072120	1.20	0.50	0.30	58.	75.	1.45	1.16	1.09	20.	25.	0.55	0.22	0.47	60.	15.	0.85	0.35	0.33	59.	61.
7082120	1.73	0.82	0.23	53.	87.	1.42	1.21	1.21	15.	15.	0.66	0.36	0.58	45.	12.	0.90	0.45	0.44	50.	51.
7092120	1.35	0.46	0.10	66.	93.	0.99	0.96	1.17	3.	-18.	0.50	0.19	0.32	62.	36.	0.50	0.20	0.25	60.	50.
7102120	2.35	0.82	0.15	65.	94.	5.26	3.03	1.67	42.	68.	0.70	0.32	0.50	54.	29.	1.00	0.58	0.38	42.	62.
7112120	0.20	0.50	0.20	-150.	0.	0.74	3.35	5.18	-353.	-600.	0.20	0.44	0.39	-120.	-95.	2.70	0.80	0.71	70.	74.
7122120	1.14	0.25	0.20	78.	82.	3.36	1.27	1.38	62.	59.	0.84	0.30	0.20	64.	76.	0.87	0.60	0.35	31.	60.
7132120	1.48	0.57	0.22	61.	85.	1.67	1.16	1.20	31.	28.	0.98	0.56	0.59	43.	40.	3.80	0.75	0.45	80.	88.
7142120	1.37	0.34	0.08	75.	94.	1.59	1.31	1.29	18.	19.	0.65	0.35	0.50	46.	23.	2.00	0.65	0.44	67.	78.
7152120	2.39	1.00	0.19	58.	92.	1.66	1.51	1.39	9.	14.	0.90	0.65	0.66	28.	27.	3.00	1.45	0.74	52.	75.
7162120	2.05	0.89	0.17	57.	92.	1.52	1.19	1.21	22.	20.	1.00	0.60	0.70	40.	30.	4.10	0.75	0.55	82.	87.
7172120	3.12	1.49	0.09	52.	97.	1.75	1.43	1.20	18.	31.	0.65	0.35	0.45	46.	31.	1.05	0.80	0.75	24.	29.
7182120	0.85	0.41	0.15	52.	82.	1.08	1.30	1.37	-20.	-27.	0.12	0.15	0.18	-25.	-50.	0.50	0.66	0.52	-32.	-4.
7192120	0.10	0.08	0.10	20.	0.	0.35	0.58	0.55	-66.	-57.	0.02	0.02	0.04	0.	-100.	0.44	0.45	0.50	-2.	-14.
7202120	1.44	1.59	0.45	-10.	69.	0.88	1.45	1.06	-65.	-20.	0.45	0.55	0.37	-22.	18.	0.76	0.75	0.54	1.	29.
7212120	2.20	1.40	0.20	36.	91.	1.90	1.41	1.38	26.	27.	1.10	0.50	0.78	55.	29.	2.77	1.10	0.55	60.	80.
7222120	1.48	0.79	0.28	47.	81.	1.56	1.35	1.80	13.	-15.	1.20	1.20	1.20	0.	0.	2.10	1.05	0.90	50.	57.
7232120	0.81	0.30	0.19	63.	77.	1.10	1.05	1.18	5.	-7.	0.21	0.30	0.68	-43.	-224.	0.56	0.85	1.02	-52.	-82.
7242120	0.06	0.09	0.09	-50.	-50.	0.18	0.42	0.78	-134.	-333.	0.12	0.15	0.10	-25.	17.	0.35	0.60	0.55	-71.	-57.
7252120	0.22	0.12	0.09	45.	59.	0.60	0.60	0.47	0.	22.	0.21	0.19	0.10	10.	52.	0.45	0.50	0.50	-11.	-11.
7262120	0.29	0.20	0.09	31.	69.	0.69	0.65	0.75	6.	-9.	0.18	0.20	0.10	-11.	44.	0.25	0.55	0.45	-120.	-80.
7272120	1.84	0.62	0.16	66.	91.	2.37	1.48	1.25	38.	47.	0.95	0.48	0.40	49.	58.	0.87	0.35	0.37	60.	57.
7282120	2.60	1.08	0.34	58.	87.	2.31	1.96	2.09	15.	10.	2.00	1.35	1.81	32.	9.	1.15	0.65	0.46	43.	60.
7292120	1.65	1.28	0.05	22.	97.	2.10	1.86	1.40	11.	33.	0.35	0.23	0.56	34.	-60.	0.43	0.30	0.15	30.	65.
7302120	1.45	0.45	0.18	69.	88.	1.40	1.60	1.95	-14.	-39.	0.70	0.55	0.84	21.	-20.	0.85	0.78	0.55	8.	35.

END OF RECORD FOR DECEMBER, 1970

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MO = MONTH
Y = YEAR
CR = CHROMIUM, MG/L
NI = NICKEL, MG/L
CU = COPPER, MG/L
ZN = ZINC, MG/L
0 = RAW INFLUENT
1 = PRIMARY EFFLUENT
2 = FINAL EFFLUENT
PR = PRIMARY REMOVAL, PER CENT
OR = OVERALL REMOVAL, PER CENT

FERRIC CHLORIDE AND ORGANIC POLYELECTROLYTES FOR THE REMOVAL OF PHOSPHORUS

GRANT NO. 11010 ENK, GRAND RAPIDS, MICHIGAN

WEIR LOADING RATES AND TOTAL PHOSPHORUS LEVELS FOR DECEMBER, 1970 , PERIOD 2

DAYPMOY	FLOW	FE+3	FLOC	POVER	SOVER	RMTP	TPO	TP1	TP2	PRTP	ORTP	RATPL
7002120	50.2	17.19	0.18	1516.	1278.	3.58	4.80	3.20	2.90	33.	40.	-0.219
7012120	43.9	17.19	0.33	1326.	1118.	2.32	7.40	2.90	3.40	61.	54.	-0.338
7022120	42.9	17.19	0.42	1296.	1092.	2.60	6.60	2.10	1.80	68.	73.	-0.564
7032120	47.0	17.19	0.31	1420.	1197.	3.24	5.30	1.80	2.10	66.	60.	-0.402
7042120	40.7	17.19	0.25	1229.	1036.	1.87	9.20	2.10	2.90	77.	68.	-0.501
7052120	39.1	17.19	0.15	1181.	996.	2.20	7.80	1.80	3.20	77.	59.	-0.387
7062120	45.2	17.19	0.40	1365.	1151.	2.39	7.20	2.40	4.50	67.	37.	-0.204
7072120	45.0	17.19	0.32	1359.	1146.	3.07	5.60	1.00	0.80	82.	86.	-0.845
7082120	45.9	17.19	0.32	1386.	1169.	2.39	7.20	2.10	2.60	71.	64.	-0.442
7092120	45.2	17.19	0.32	1365.	1151.	2.49	6.90	2.60	1.80	62.	74.	-0.584
7102120	44.6	17.19	0.30	1347.	1285.	2.82	6.10	2.40	1.60	61.	74.	-0.581
7112120	46.8	17.19	0.38	1413.	1490.	2.49	6.90	3.20	0.50	54.	93.	-1.140
7122120	41.0	17.19	0.31	1238.	1305.	2.15	8.00	3.20	1.60	60.	80.	-0.699
7132120	47.0	17.19	0.43	1420.	1496.	2.69	6.40	1.80	2.60	72.	59.	-0.391
7142120	46.7	17.19	0.20	1410.	1487.	2.96	5.80	3.40	2.10	41.	64.	-0.441
7152120	46.1	17.19	0.31	1392.	1328.	2.96	5.80	3.70	2.90	36.	50.	-0.301
7162120	49.1	17.19	0.31	1483.	1250.	2.82	6.10	3.20	2.60	48.	57.	-0.370
7172120	49.2	17.19	0.33	1486.	1253.	3.07	5.60	1.60	1.00	71.	82.	-0.748
7182120	53.2	17.19	0.33	1607.	1355.	2.82	6.10	1.80	1.60	70.	74.	-0.581
7192120	44.9	17.19	0.33	1356.	1143.	1.53	11.20	1.80	1.30	84.	88.	-0.935
7202120	48.2	17.19	0.32	1456.	1227.	3.58	4.80	2.90	2.00	40.	58.	-0.380
7212120	50.8	17.19	0.33	1534.	1294.	2.69	6.40	3.40	1.60	47.	75.	-0.602
7222120	49.2	17.19	0.31	1486.	1253.	2.69	6.40	3.40	1.60	47.	75.	-0.602
7232120	43.4	17.19	0.33	1311.	1105.	2.49	6.90	1.60	1.00	77.	86.	-0.839
7242120	38.0	17.19	0.33	1148.	968.	3.82	4.50	1.00	0.80	78.	82.	-0.750
7252120	38.7	17.19	0.33	1169.	985.	2.60	6.60	1.00	0.80	85.	88.	-0.916
7262120	38.2	17.19	0.33	1154.	973.	2.96	5.80	2.10	0.50	64.	91.	-1.064
7272120	44.7	17.19	0.33	1350.	1138.	2.15	8.00	2.10	1.30	74.	84.	-0.789
7282120	46.0	17.19	0.33	1389.	1171.	2.69	6.40	3.40	2.60	47.	59.	-0.391
7292120	44.8	17.19	0.33	1353.	1141.	2.46	7.00	4.50	2.60	36.	63.	-0.430
7302120	41.3	17.19	0.31	1247.	1052.	2.82	6.10	1.80	1.30	70.	79.	-0.671

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MO = MONTH
Y = YEAR
FLOW = DAILY AVERAGE FLOW, MGD
FE+3 = FERRIC IRON, MG/L
FLOC = PURIFLOC A23 FLOCCULANT, MG/L
POVER = PRIMARY OVERFLOW RATE, GAL/DAY/FT2
SOVER = SECONDARY OVERFLOW RATE, GAL/DAY/FT2
RMTP = RATIO OF FERRIC IRON/RAW TOTAL PHOSPHORUS
TP = TOTAL PHOSPHORUS, MG/L
0 = RAW INFLUENT
1 = PRIMARY EFFLUENT
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OR = OVERALL REMOVAL, PER CENT
RATPL = LOG FRACTION TP REMAINING IN FIN. EFF.

*U.S. GOVERNMENT PRINTING OFFICE: 1974 546-339/397 1-3